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APRIL 1926

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American Institute of Electrical Engineers

COMING MEETINGS

Annual Business Meeting, New York, N. Y., May 21

Annual Convention, White Sulphur Springs, W. Va., June 21-25

Pacific Coast Convention, Salt Lake City, Utah, (Sometime in September)

Regional Meetings

Great Lakes District, Madison, Wis., May 6-7

Northeastern District, Niagara Falls, May 26-28

MEETINGS OF OTHER SOCIETIES

International Electrotechnical Commission, Engineering Societies Bldg., New York, April 13-22

National Electric Light Association, Atlantic City, May 17-21

Middle West Division, N. E. L. A., Ft. Des Moines Hotel, Des Moines, Ia., April 7-9

Southwestern Division, N. E. L. A., Galveston, Texas, April 13-16

Southeastern Division, N. E. L. A., Pinehurst, N. C., April 27-29

Nebraska Section, N. E. L. A., Lincoln, April 29-30

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV APRIL, 1926 Number 4

The Ideals of the American University*

What, then, is the mission of the American University? Comparing the American college with the American university one is reminded of Janus, the old Roman deity, the guardian of the entrance to the Roman home. In the early dawn of Roman history this deity had one face only, but as the Roman home grew bigger a second face appeared. The American college and the American university are the two faces of the same guardian angel; one face contemplating reverently the familiar past and the other anxiously exploring the unknown future of this nation. The college perpetuates the national idealism of the past, the university prepares its future expansion. This idealism is the bond between the two, and without this bond they lose their spiritual meaning.

Lincoln closed his Gettysburg speech with the following warning:

> "It is rather for us to be dedicated to the task remaining before us . . . . that this nation, under God, shall have a new birth of freedom,—and that government of the people, by the people, for the people, shall not perish from the earth."

A dedication to so exalted a task demanded an expansion of our inherited national idealism. It is not surprising that the generation which heard this warning saw also the birth of the first real American university. The most comforting response to Lincoln's warning was a series of events which should be recorded with red letters in American history. The earliest among these events is the foundation, under a Congressional Charter, of the National Academy of Sciences in the same year in which Lincoln delivered his immortal speech. Lincoln, our greatest idealist in political philosophy, and Joseph Henry, his personal friend, our greatest idealist in science in those days, were the sponsors of this national organization whose members were always devoted to the cultivation of idealism in American learning. Some of the most distinguished members of this organization like Joseph Henry, John William Draper, Frederick Barnard, and Andrew White started that great movement for higher endeavor which found its first visible expression in the foundation of Johns Hopkins University in 1876, the first real university in the United States. Every student of the history of American idealism should know the life of Daniel Coit Gilman, at one time president of the University of California, who became the first president of Johns Hopkins University and presided over a faculty of idealists of the highest order of magnitude.

The aim of these idealists was the cultivation of idealism in every department of American learning, in order to prepare this nation for the expansion of the early American idealism which Lincoln glorified in the first lines of his Gettysburg ode. How did the nation respond? In less than a decade a score of American universities sprang into existence and followed the example of the idealists of Baltimore. This sudden outburst in the higher intellectual activities of our young universities encourages the belief that the period inaugurated by the termination of the Civil War witnessed an Intellectual Renaissance in the United States. The catalogue of its achievements during the last fifty years is as long as Homer's catalogue of the ships which carried the Greek heroes to the plains of Troy. Neither time nor purpose permit its recital here. There is one achievement, however, which I must mention.

Nothing resists a change as obstinately as the mental attitude of man. The history of science from Archimedes to Newton offers many illustrations of this wellknown fact. The change in the mental attitude of our age is one of the greatest achievements of our Intellectual Renaissance. Less than two generations ago educational training was expected by many to operate like a penny in the slot machine, that is, learn your lesson and convert your learning into cash without much delay. The so-called practical man who managed our American industries was at that time an ardent advocate of this utilitarian theory. He worshipped the art of making a living. Franklin and Lincoln, my patron saints, had no sympathy with this theory. The art of making a living was not the determining factor in their schooling, but the art of making life worth living was everything to them. They would find no fault with the American college, because its diploma does not testify that college graduates are loaded with a knowledge of the art of making a living, provided, however, that they carry with them some definite ideas about the art of making life worth living, not only their own individual life but also the life of our nation. The expansion of these ideas is the gospel of the American university. The Philistines, the so-called practical men of two generations ago, could not resist the power of this gospel; they have been converted, and this conversion is a great triumph of the apostles of our American universities.

The idealism of the Christian gospel which St. Paul and St. Peter preached was not clearly understood until the world had seen it in operation in the lives of those who had embraced it. The idealism of the American university was not clearly understood by the so-called practical man until he had seen it in operation in his dearly beloved industries. Motive, mental attitude, and method of work form the tripod upon which this idealism rests. But a motive which means unselfish search of the truth; a mental attitude which demands open minded communion with nature and freedom from prejudice; a method of work which in the hands of men like Archimedes, Galileo, Newton, Faraday and their disciples conferred innumerable blessings upon mankind; all these things were too abstract for the socalled practical man. But presently industrial problems arose the solution of which demanded the subtle touch of the university idealist; the stubby hand of the practical man had tried to handle them and it failed. The idealist showed the way, and from that time on the American industries began to worship at their altar of idealism of the American universities. Today that idealism is their patron saint who guides them in their progress; it will soon perform a similar service in all the activities of our nation, including our national politics, and lead us to that ideal democracy which was the dream of Lincoln.

Your distinguished fellow citizen of California, Secretary Hoover, is a practical man, but he has nothing in common with our practical men of two generations ago. In his recent appeal to this nation he preached a gospel which may be summed up as follows; Cultivate the fundamentals in the research laboratories as well as in the lecture rooms. This will lead us to the truth which will give this nation a new birth of freedom, and will raise our democracy to the lofty level of Lincoln's ideal.

M. I. Pupin

*Abstract from a Charter Day address delivered at the University of California, March 23, 1926.

Some Leaders of the A. I. E. E.

Ralph Davenport Mershon, the twenty-fifth President of the A. I. E. E. was born in Zanesville, Ohio, July 14th, 1868. He was educated in the public schools of his native place, and began his engineering career at the age of 17 as a member of an engineering corps engaged in railway location and construction. In 1886 he entered the Ohio State University, from which institution he graduated in 1890 with the degree of M. E. During the last year of his University course, he was Student-Assistant in Physics and Electrical Engineering, and for one year after graduation, (1890-91), he was Assistant instructor of Electrical Engineering.

During 1891-1900, he was employed by the Westinghouse Electrical and Manufacturing Company of Pittsburgh. While with this company, Mr. Mershon became experienced in all branches of electrical work;—research work, both theoretical and practical,—experimental work, designing, factory engineering, field engineering and installation, patent expert work and patent experimental work, commercial work and selling. The transformers for which the Westinghouse Company received an award at the World's Columbian Exposition at Chicago in 1893 were of his design.

In 1893-95, he had charge of certain work being done by the Westinghouse Company in connection with the extension of the transmission plant of the Telluride Power Transmission Company of Telluride, Colorado. This was a single-phase, alternating-current transmission, employing single-phase, synchronous motors.

In 1896-97 for the Telluride Power Transmission Company and the Westinghouse Electric and Manufacturing Company he carried on at Telluride an investigation of the phenomena which occur between conductors at high voltages. This investigation was made on a transmission line about two and one-half miles long, and was the first investigation in which quantitative measurements of the ionization and other atmospheric losses occurring between conductors at high voltages were obtained. Original methods of investigation were devised by Mr. Mershon for this work, and special apparatus designed and built by him, by means of which quantitative measurements were made up to 72,000 volts. At the completion of the quantitative work, the voltage was carried up to 133,000 volts, at that time by far the highest voltage that had ever been impressed on an outdoor line.

In 1897-98, securing leave of absence from the Westinghouse Company, he acted as chief engineer of the Colorado Electric Power Company, during the designing and installation of their transmission plant which generates current by steam at Canon City, Colorado, and transmits power at 25,000 volts to Cripple Creek, Colorado, (a distance of 25 miles), where it is used for mining.

From 1898 to 1900, Mr. Mershon was engineer of the New York office of the Westinghouse Electric and Manufacturing Company, but during the latter year he resigned to enter upon private practise as a Consulting Electrical and Mechanical Engineer in New York City.

Some of the more important pieces of engineering work accomplished by him since entering practise as a Consulting Engineer are:

The reconstruction and enlargement of the water wheel, generating, transforming and transmitting equipment of the Montreal and St. Lawrence Light and Power Company (now a part of the Montreal Light, Heat and Power Company), transmitting to Montreal, a distance of 17 miles, 20,000 horse power at 25,000 volts;

The design and supervision of the first transmission plant of the Shawinigan Water and Power Company, transmitting power at 50,000 volts a distance of 85 miles to the City of Montreal.

The design and installation of the substation equipments of the Montreal Street Railway Company, having an aggregate capacity of about 12,000 horse power, for utilizing power transmitted to Montreal from various hydraulic plants;

The design and supervision of the transmission plant of the Niagara, Lockport and Ontario Power Company for transmitting power at 60,000 volts from Niagara Falls to various points in New York State. This plant is the largest transmission plant ever undertaken anywhere in point of capacity, and is one of the most important in point of distance of transmission. Its initial capacity was 60,000 horse power, and it is laid out for an increase to 180,000 horse power. At present its longest feeder is 160 miles.

The electrical design of the generating station, transmission line and receiving stations of the Inawashiro Hydroelectric Power Company, transmitting power at 115,000 volts from Lake Inawashiro to Tokyo, Japan, for use in the latter place,—a distance of 140 miles. The initial installation was for 45,000 kw.

In 1905, and for several years thereafter, he was retained on the work of the Victoria Falls Power Company, in connection with the installation of their steam stations near Johannesburg for supplying power to the gold mines of the Witwatersrand, and in connection with the proposed transmission of power from Victoria Falls on the Zambesi River, Rhodesia, South Africa, to the Rand, for operation in connection with these steam stations; being then the only American engineer so retained.

Mr. Mershon is the author of a number of technical papers, among which are "The Output of Polyphase Generators and Rotary Transformers," 1895. This paper contained the first published analysis of the effect upon the output of closed coil windings, when the number of phases is varied.

"Drop in Alternating Current Lines," 1897, treating of the calculation of drop and giving a table and chart by means of which such calculations can be quickly and accurately made.

"The Maximum Distance to which Power can be Economically Transmitted, 1904. This paper was presented at the International Electrical Congress at St. Louis in 1904, and was read before the American Institute of Electrical Engineers the same year. In presenting this paper at the International Electrical Congress, Mr. Mershon represented the American Institute of Electrical Engineers, acting as its delegate to the Congress.

"High Voltage Measurements at Niagara," his paper read before the American Institute of Electrical Engineers, June 30th, 1908, gives the result of some three years of investigation of the ionization and other atmospheric losses occurring between line conductors at high voltages. This was a continuation of the work previously done by Mr. Mershon at Telluride.

Previous to the entry of the United States into the World War, Mr. Mershon actively cooperated with those who formulated, and procured the passage of, the legislation creating the Reserve Officers Training Corps. Subsequently, when a Joint Committee of the National Engineering Societies was formed to work for the establishment of an Officers Reserve Corps he was a member of that Committee and active in the work which led to the passage of legislation creating the Corps. He was among the first of the Majors—then the highest rank in the Corps—commissioned in the Engineer Officers Reserve Corps.

When the United States entered the War, he was called to service and detailed to the Naval Consulting Board for the especial purpose of directing the work of the Special Problems Committee of the Board, which had principally to do with the problem of submarine detection. At the time of his retirement from military service he had the rank of Lieut. Colonel of Engineers.

He is a member and past president of the Inventors Guild and also a member of many American and foreign technical Societies.

The Development of the Sectional Paper-Machine Drive

BY H. W. ROGERS[1]
Associate, A. I. E. E.

Synopsis.—*To an increasing degree, large machines designed for quantity production are being subdivided into their elements, each section being driven by a separate motor as contrasted with former practise of driving these machines, as a whole, from a single unit. With the paper machine, this is called the sectional-electric drive.*

In this paper, the author has confined himself largely to the history and development of the several types of the sectional drive and the relative merits of each particular type.

An attempt has been made to set forth clearly the advantages of the sectional drive and to show that its field of application should increase with a fuller understanding of its advantages as to increased production, improved product and lower operating cost.

* * * * *

THE sectional drive, as it is commonly called, consists of a number of individual motors driving the various sections of a single machine with provision for maintaining a definite speed relationship between the sections, and while it is not limited in its application to paper machines, the use of it in this industry has been so extensive that it is impossible to mention sectional drives without immediately thinking of the paper industry.

The sectional drive is an extremely interesting engineering problem and is very important commercially, especially to the pulp and paper industry. Of approximately 1600 paper machines in use at the present time, probably 80 per cent are still being driven by means of the old type mechanical drive and steam engine, which would indicate that, in spite of the progress already made, the field of application for the electric drive has barely been entered.

The advantages of the electric motor are recognized, as practically all new mills are 100 per cent electrically equipped and most old mills use motors to a limited extent on pumps, beaters, jordans, screens, etc. However, the paper machine, the most important machine in the mill and the heart of a billion dollar industry, has been neglected. A vast amount of time and thought, research and development work, has been devoted to this problem by the engineers of some of the larger electrical manufacturers and, like all other new applications, developments, changes and refinements have taken place.

In a sense, these changes have come as the result of a broader knowledge of the problem and an honest endeavor to meet all of the requirements, but it is equally true that the paper manufacturers have gradually become more exacting in their requirements. In any event, change and development go hand in hand with progress; it is a natural process and should not be held out as a criticism.

To appreciate fully the problem which confronted the electrical manufacturer in 1919, it is necessary to consider the details of the paper machine and its requirements.

There are certain parts of every paper machine which run at a constant speed, regardless of the speed at which paper is being produced, and these parts, consisting of screens, pumps, suction and agitators constitute what is commonly called the constant-speed end of the paper machine. The driving of this end of the machine presents no difficulty whatever in its application and requires very little attention.

The variable-speed end of the machine consists of a number of separate sections, which have been in the past and are very largely at the present time being driven from a single line shaft through a system of cone pulleys and bevel gears with friction clutches for starting and stopping each individual section separately if occasion requires.

The stock enters the machine at the wet end on the wire and consists of 99½ per cent water and ½ per cent stock. Here the sheet is formed and, in three seconds, 99 per cent of the water is removed after which the sheet passes through one or more press rolls and over the dryers to the calenders, reel and rewinder as finished paper with about 8 per cent moisture, the whole operation requiring probably 40 seconds.

A continuous sheet must, therefore, be maintained throughout the machine and owing to its condition, there is a slight difference in speed between each section which must be maintained absolutely. This difference in speed is called "draw" and varies from time to time with the condition of the stock and the grade of paper and must, therefore, be capable of adjustment.

The drive must not only permit of a very close speed regulation, but must also permit of adjusting the "draw" between sections and at the same time absolutely maintain the relative speeds of the various sections.

The quality of the product depends very much upon the type of drive selected and the proper application of it with respect to the machine. Speed regulation, flexibility of control and uninterrupted service are all important factors and must be given careful considera-

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1. Industrial Engineering Department, General Electric Company, Schenectady, N. Y.

Presented at the Regional Meeting of District No. 2 of the A. I. E. E., held at Cleveland, Ohio, March 18-19, 1926.

tion. For this reason it is desirable to have the paper machine and its drive a complete unit in itself, independent of the rest of the mill, so that trouble in the rest of the mill will not result in any interruption in the actual production of paper.

The line drawing, Fig. 1, illustrates the more common form of paper machine, consisting of the following sections:

1. Couch (either suction or standard)
2. First press (either suction or standard)
3. Second press
4. Third press
5. First dryer
6. Second dryer
7. Calender
8. Reel.

A fourth, and even a fifth press is sometimes encountered, and it is not uncommon to find a smoothing press with one or two breaker stacks and two or three calendar stacks, making a total of twelve or thirteen sections on one single machine. These sections, however, are practically independent of each other so that they are readily controlled, but on machines which involve felts common to two or more sections, the problem becomes complicated and both the paper manufacturer and the electrical manufacturer begin to court trouble.

The "draws" or slight variations in speed between consecutive sections are not fixed but are subject to modification due to the condition of the stock, kind of paper and suction; consequently, provision must be made to vary the speed of each individual section within certain limits (approximately 20 per cent) and still maintain a definite speed relationship between all of the sections. The approximate draws are indicated in Fig. 1.

The driving of a single machine with a multiplicity of motors, or a sectional drive as it has come to be known, is not a new idea, although the demand for it is relatively recent, beginning in 1919.

In 1909 the first real sectional drive was installed at the Chisholm Falls plant of the International Paper Company, consisting of d-c. motors with quarter-phase collector rings and mechanical speed changers for "draw" adjustment and, although it operated successfully for months, it was evidently in advance of the times and was eventually taken out.

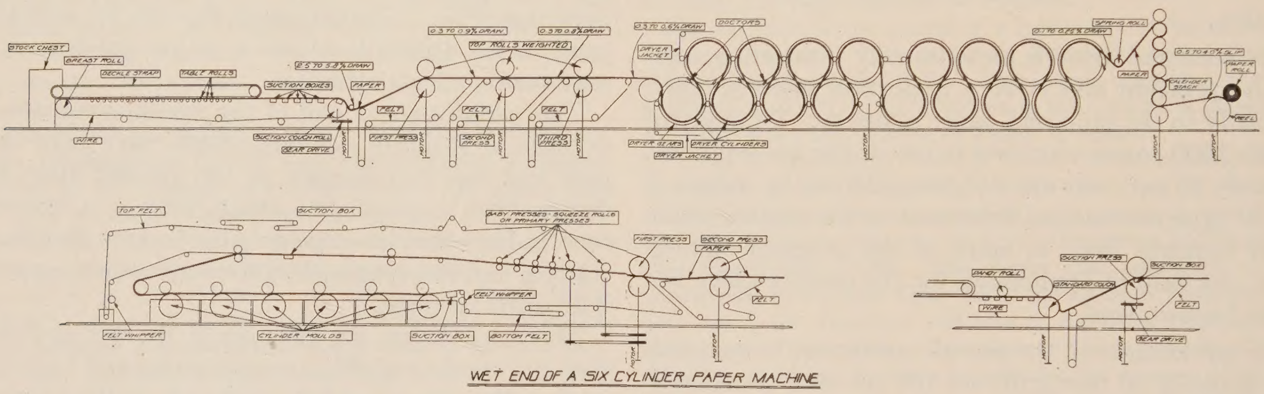

Fig. 1—Fourdrinier Paper Machine

In 1919 the enormous demand for paper, which had been aggravated by the curtailment of paper machine production during the war, started a controversy regarding the relative merits of wide, slow-speed machines and narrow, high-speed machines. Needless to say, the high-speed machine won out, although there is now a mild tendency to reverse that decision, and the demand for sectional drives was born at a time when most of the electrical manufacturers were not fully prepared to receive it.

It was frankly admitted among machine builders and operators that while the mechanical drive was a possibility on high speed machines, it was not at all practical on account of the high maintenance and this condition magnified the necessity for a solution to the problem.

There was no reliable power data available, since it was practically impossible to obtain any with mechanical drives; nor was there any accurate data on "draws" for the same reason. However, the need was urgent and the first so-called synchronous tie-in type of paper-machine drive, in spite of adverse criticisms and prophesies to the contrary at the Crown-Willamette Paper Company's Mill was built and put into successful operation. This drive was really the forerunner of the ever increasing demand that has spread over the entire country, including Canada, and its success has had a marked bearing upon the development of the industry and the attitude of the trade toward sectional drives in general. A failure at that time would have been a reflection upon the electrical industry as a whole and undoubtedly would have been a serious set-back to the sectional drive as such.

In theory this type of drive was all that could be desired; in practise it fulfilled all expectations and its success was duplicated in eleven other orders during the same year. These drives made it possible to secure a vast amount of valuable data heretofore unavailable, the careful analysis of which has had a great deal to do with the developments that have followed since their creation.

During this period drives of an entirely different character were being exploited, although not in such large numbers.

Strictly speaking, there are but two types of sectional drive on the market today:

I. The synchronous tie-in type of drive, wherein there is an actual interchange of energy between the various machine sections and where the relative speeds are held constant by synchronous motors. This, truly, is preventative rather than corrective.

II. The regulator type of drive, wherein the speed of the various sections is maintained by shunt field adjustment on the motors. It will operate on an angular displacement similar to Type I, if the regulator element is of the synchronous type, but there is no actual restraining power to hold the motor in place and the success or failure of this type is determined by the amount of angular displacement which causes the regulator to function and by the time element of the motor field.

The real difference between these two types of drive even where instantaneous load changes are encountered, whereas the regulator type of drive requires a certain time element between the change in load and the correction. However, the regulator type of drive, which will be fully treated later in this paper, has been improved to a point where it meets the most exacting requirements of commercial operation and, despite the larger capacity driving motors which it requires for wide range machines, offers advantages as to first cost and space requirements.

Coincident with the development of the regulator type of drive, the synchronous tie-in drive, while remaining fundamentally the same, has passed through several stages of improvement.

I. The original type consisted of slow-speed d-c. motors with high-speed synchronous tie-in motors connected to the d-c. motor through a pair of cone pulleys and a gear reduction.

II. In the second development the cone pulleys and belts were eliminated and a high-speed synchronous motor with revolving stator frame was used, the stator

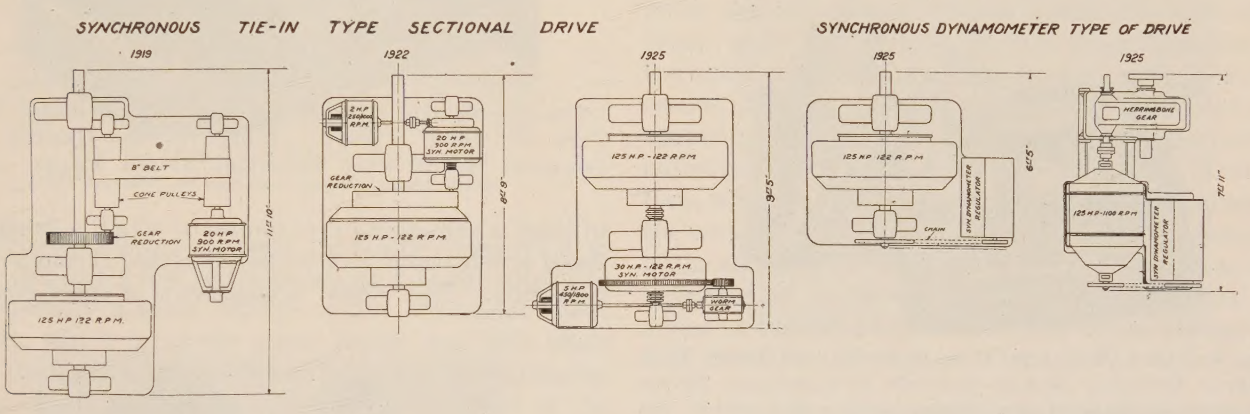

Fig. 2

can readily be appreciated when the peculiar characteristics of the d-c. motor, operating at reduced voltages and speeds, are considered. The speed regulation at full voltage and full speed may be three or four per cent or even less, but, owing to the armature drop, it becomes extremely poor when operating at low speeds on low armature voltage. To maintain a constant speed under these conditions with a varying load requires a very wide change in the field strength which detracts from the motor torque at low speeds. In other words, a d-c. motor will not deliver as much torque under reduced armature voltages and this demands the use of over-capacity motors where the regulator type of control is used.

With the synchronous tie-in type of drive, the motor capacity need not be increased because the synchronous motors absorb the change in load and the d-c. motors may be operated at a fixed field. This type of drive, therefore, while higher in cost and space requirements has the advantage of smaller capacity motors and will hold the motor speed within extremely close limits frame being driven by a small adjustable-speed d-c. motor. This change reduced the space requirements and overcame the objection to belts.

III. The final development of this type of drive utilizes a slow-speed synchronous motor mounted on the d-c. motor shaft, thus eliminating the gear reduction.

On all three of these drives the synchronous motors were 20 per cent of the capacity of the main driving unit with 200 per cent pull-out torque either as a motor or as a generator; consequently, they could take care of a maximum load change of 40 per cent without exceeding their normal rating and still hold the speed within very close limits. The development of this type of drive is shown in Fig. 2.

It is a well-known fact that the synchronous motor operates at a fixed speed which is dependent upon, the frequency of the system to which it is connected and the speed cannot be changed so long as it operates within its capacity. The use of a multiplicity of synchronous motors connected to the same source of supply or interconnected between each other is analogous to a mechan-

ical line shaft and gears connecting the various sections of a machine together.

It is true that the loading of a synchronous motor is accomplished by an angular displacement between the rotor and stator, but it is equally true that a mechanical shaft with gears is subject to angular displacement under load.

The angular displacement in a synchronous motor is perhaps 10 or 12 electrical deg. under full-load conditions which corresponds to an angular displacement on the main driving motor of less than one-half of a mechanical degree. This displacement affects the sheet of paper that is passing over the roll at the time the load change occurs, and is present in all types of drive whether mechanical or electrical. It, however, is a negligible quantity and has no bearing upon the operation.

The original type of drive which has been so successful from the beginning has been installed on twelve paper machines, although one of them has since been

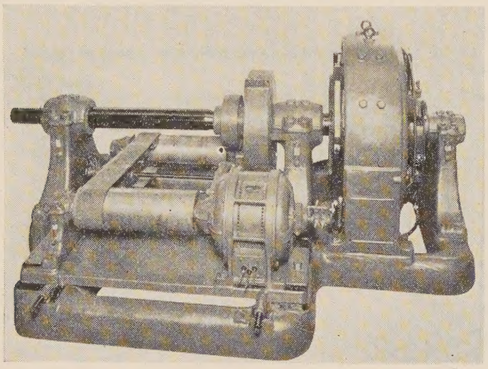

Fig. 3—First Development of Synchronous Tie-in Type of Drive Showing Moderate-Speed Synchronous Motor Connected to Main Motor Through Gear Reduction and Cone Pulleys

modified to the regulator type for the sake of uniformity in equipment. The use of cone pulleys and belts between the main driving d-c. motors and the synchronous tie-in motors has been questioned in a few instances on the basis that belts in ordinary commercial service operate with a slip of two or three per cent. However, the belts used on these drives are very much over capacity and under actual test show a maximum slip of $\frac{30}{100}$ of one per cent. The load on a paper machine is very constant and under normal operating conditions will not vary more than 10 per cent. Consequently, the speed is maintained with $\frac{15}{100}$ of one per cent or less, whereas the same load change on a mechanical drive would be twice this amount or even more depending upon the condition of the belts. Each synchronous motor is free to act as a motor or a generator with an actual transfer of energy between it and the balance of the synchronous motors. A load change on one section, therefore, may affect the speed of that section $\frac{15}{100}$ of one per cent, but the effect on the remaining sections, which must of necessity supply or absorb the energy, is only $\frac{2}{100}$ of one per cent on an eight section machine.

The second development of synchronous tie-in drive

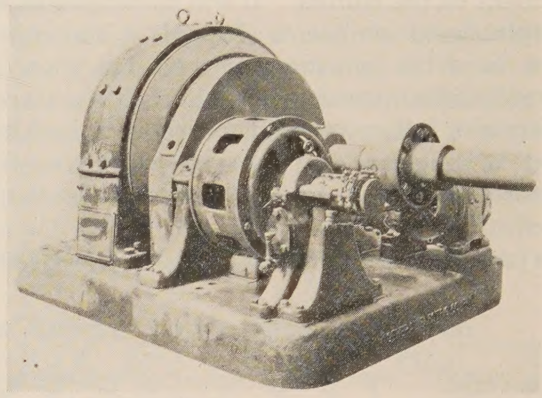

Fig. 4—Second Development of Synchronous Tie-In Type of Drive Showing Moderate-Speed-Geared, Synchronous Motor with Revolving Stator Frame

utilized a slow-speed d-c. motor to which a moderate-speed synchronous motor was connected through a gear reduction. The "draw" adjustments or speed changes,

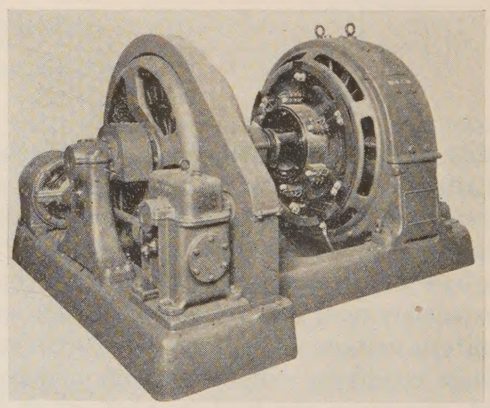

Fig. 5—Third Development of Synchronous Tie-in Type of Drive Showing Slow-Speed, Direct-Connected Synchronous Motor with Revolving Stator Frame

were obtained by rotating the stator frame of the synchronous motor by means of a small adjustable speed d-c. motor. This change eliminated the cone pulleys and belts and had the advantages of smaller space requirements and "draw" adjustment through the medium of a field rheostat rather than the shifting of a belt.

This type has been in successful operation since 1922 and has also been furnished on two other machines.

The third and final development of the synchronous tie-in drive utilizes a slow-speed d-c. motor and a slow-speed synchronous motor mounted on the same shaft. The "draw" adjustment is obtained by rotating the stator frame of the synchronous motor by means of a small adjustable speed d-c. motor. In this drive the cone pulleys, belt and the gear reduction are eliminated. This drive has been furnished for four paper machines which are motored for 1440 ft. per min., a speed far in excess of anything that has ever been attempted in the past on any machine.

In both of these developments where revolving-frame

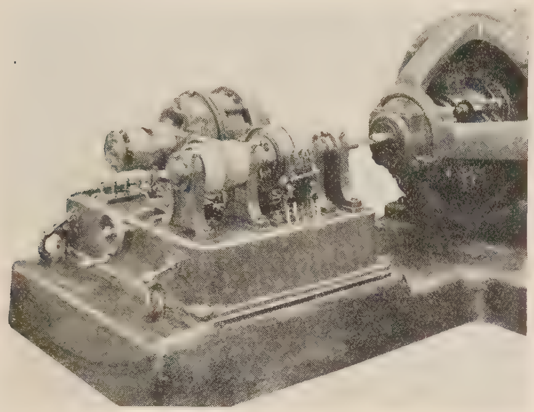

FIG. 6—DISK-TYPE SPEED REGULATOR
As installed on sectional paper-machine drives

synchronous motors are used, the stator frame revolves at an extremely low speed compared with the rotor and consequently a speed change on the adjustable speed motors, which drive the stator frame, has little effect upon the speed of the section. In reality the regulation of the small d-c. motor only affects the speed of the stator which is but a small percentage of the synchronous speed. Consequently, the synchronous speed or the speed of the main driving motor will be maintained within $\frac{15}{100}$ of one per cent or less for the load changes ordinarily encountered on a paper machine.

Fifteen of these drives are now in successful operation and most of them have been operating for five years with practically no maintenance.

THE SYNCHRONOUS DYNAMOMETER (REGULATOR) TYPE

The possibilities of a speed regulator which operates on the shunt field of a d-c. motor have been fully appreciated and as early as 1920 a synchronous dynamometer type of speed regulator was built by the company with which the writer is connected.

This regulator consisted of a small synchronous motor, the rotor of which was driven from the motor on which the speed was to be held constant through a pair of small cone pulleys and a small belt. The stator was excited from a master generator in such a way that it remained stationary unless there was a tendency for the controlled motor to change in speed, thereby causing the stator to rotate and alter its field to maintain the speed constant. It operated on an angular displacement and handled the field current direct through a commutator type of rheostat, the brush mechanism of which was connected direct to the synchronous motor stator.

In 1921-1922, the disk-type regulator with synchronous motor actuating element followed closely on this development operating on the principle of a voltage regulator, except that the contacts were revolving instead of stationary. In its developmental stage the disks were modified to give a total angular displacement of 180 degrees and were so constructed as to cut the motor field resistance in and out of the field circuit twice every revolution or twenty times a second, the effective field resistance being determined by the angular displacement between the disks, one of which was driven by the motor to be controlled and the other by the synchronous motor. Subsequently, the brush mechanism was altered to cut the resistance in and out in three steps rather than one.

During 1922-23 this final form was furnished with ten paper machine drives, making newsprint, book, kraft, tissue, crepe and glassine; on high-speed machines and low-speed machines, for narrow-range and wide-range speeds. The regulator was subject to limitations in its operating range, under some conditions necessitating adjustments in an auxiliary field rheostat. This feature, however, only applied to wide-range machines and the endeavor to overcome it and make the adjustment of the auxiliary rheostat automatic resulted in one more development in which a mechanical differential was added to the disks to automatically adjust the external field rheostat. It was built and tested under actual

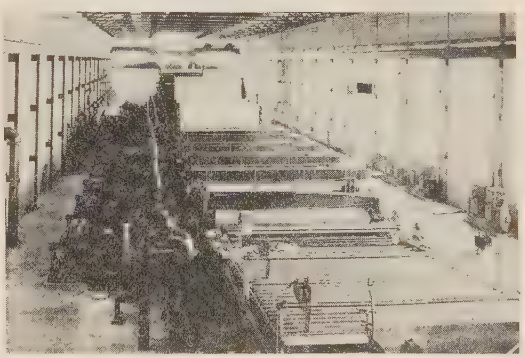

FIG. 7—SYNCHRONOUS TIE-IN TYPE OF DRIVE WITH CONE PULLEYS AND BELTS
As installed on a 164-in., 1200-ft.-per-min. paper machine

operating conditions but has never been furnished on any drive.

As a result of past experience with all kinds of paper machines making all grades of paper, it is believed that the speed regulator which will best satisfy the exacting conditions of operation and appearance is the development and refinement of the synchronous dynamometer regulator built and tested in 1920 and known as a synchronous dynamometer. It consists of a small synchronous motor, the rotor of which is driven from

the motor to be controlled through a pair of cone pulleys and a belt which gives 20 per cent "draw" adjustment. The stator frame, mounted on ball bearings is excited from a master generator and is free to rotate. It actuates the brush mechanism of a commutator type rheostat which has a total movement of 180 deg. The rheostat has both coarse and fine steps and gives the equivalent of 450 operating points.

This regulator combines a number of features not found in any other type of regulator:

1. Is of the synchronous type
2. It operates on an angular displacement corresponding to approximately 0.05 per cent change in speed of the controlled motor
3. Has 450 operating points
4. Has anti-hunting features
5. Has an absolute minimum of moving parts as the rotor of the synchronous motor, which is mounted on ball bearings, is the only moving part
6. The rheostat mechanism is stationary except when load changes demand action. It is not of the make and break contact type
7. Remains stationary, maintaining its operating position when the master generator is shut down or when the synchronous motor is disconnected from its power supply, thus overcoming any possibility of a "wild" machine

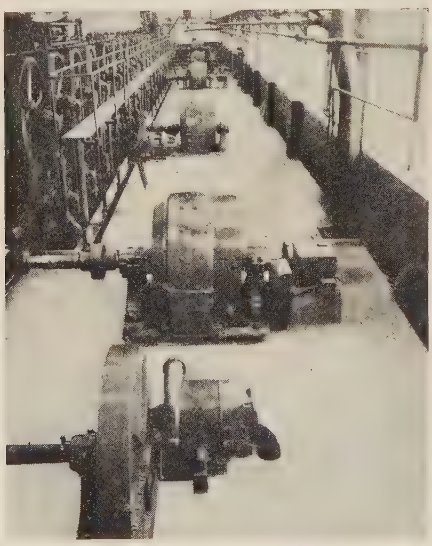

Fig. 8—Regulator Type of Sectional Drive

As installed on a 170-in., 700-ft-per-min. machine

8. Has a wide operating range
9. Low maintenance
10. Minimum space requirements
11. Is totally enclosed
12. Is mounted direct on the motor base
13. Presents a neat compact appearance
14. Is readily accessible
15. Is rugged in design
16. Has motor-operated "draw" adjustment.

It would seem that there has been an unusual number of modifications in the sectional drive but a careful analysis of the situation will reveal that there have been from the very beginning but two distinct types. The changes that have taken place are a natural process of development and do not affect the fundamental principle of operation.

Thus far only the development of the two types of drive and their characteristics as separate units have been given consideration, without any particular reference to the machine as a whole.

Fig. 9—Control Switchboard for Sectional Paper Machine Drive

The sectional drive usually consists of the various parts as enumerated below.

I. A Turbo Generator Set.

(a) This has a separately excited shunt-wound d-c. variable voltage generator and a non-condensing steam turbine with a direct-connected exciter of sufficient capacity to excite the generator and all of the sectional motor units.

Exhaust steam is utilized to dry the paper and the turbine is designed to operate at back pressures to meet the required conditions. In some instance an a-c. generator is also furnished as a part of the turbine unit to furnish power to the constant speed end of the paper machine or to float on the mill system and thereby insure a perfect steam balance under all conditions of operation.

Synchronous motor-generator sets are sometimes used as prime movers and in such cases either live steam or exhaust steam from some other source is used to dry the paper.

(b) A generator-control panel

(c) A voltage-regulator panel with

1. A voltage regulator for the main generator
2. A voltage regulator for the exciter

(d) An auxiliary control panel for controlling the generator voltage and the speed of the machine as a unit.

II. Motor Equipment.

(a) An adjustable speed, d-c. motor for each section of the paper machine. This may be of the slow speed direct-connected type or of the moderate speed geared type. Both the open type motor and the enclosed, externally ventilated type motors have been furnished,

but this is entirely a matter of preference with the paper manufacturer.

(b) A regulator.

III. Mechanical Parts.

All motors are furnished with base, shaft, bearings, couplings, shaft extensions, and all necessary equipment not included as a part of the paper machine.

IV. Control.

(a) A five-point, full automatic-contactor control panel with overload and under voltage protection and indicating meters for each sectional motor unit.

(b) A continuous duty starting and regulating rheostat designed for 75 per cent speed reduction for each sectional motor unit.

V. Master Generator Set.

The master generator set which supplies a-c. power to the speed regulators consists of a 10-kw., 1200-rev. per min., three-phase, 60-cycle generator, direct connected to an over capacity d-c. motor which is controlled from the main generator panel and automatically comes up to speed when the voltage is brought up on the generator.

It controls the speed of the paper machine as a unit and its speed is adjustable within certain limits although it depends primarily upon the voltage at which the main generator is operating.

When the synchronous tie-in type of drive is used, the master generator is not necessary because any one or more sections which happen to be running constitute a master for controlling the speed of the other sections.

VI. Draw Adjustment.

Provision is made on each sectional unit for a sufficient "draw" adjustment to take care of all operating conditions such as variations in stock, grade of paper, grinding press rolls and the like.

The "draw" adjustment is motor operated and may be made from the front side of the machine.

VII. Temperature.

All equipment is based on 40 deg. cent. rise under normal load.

VIII. Location of Equipment.

The power unit should preferably be located in the basement under the paper machine and in close proximity to this unit the generator control and all of the motor control units may be lined up as a single switchboard. This arrangement leaves nothing in the machine room except the motor equipment and the control buttons.

IX. Operation.

In starting up the paper machine it is to be assumed that the motor-generator set or turbo generator set is running and that there is a proper voltage supply available. Each section of the paper machine may be started up in succession, starting with couch, by merely pressing a button after which the motor automatically comes up to its full speed or to a speed corresponding to the supply voltage and the speed regulator is automatically connected to the master generator bus and begins to function immediately.

Provision is made to operate the motors at slow speeds for washing felts, changing wires or spearing broke.

The individual control of the motors permits of operating any section of the paper machine independent of any other section and at the same time assures an absolute synchronous tie-in between the sections when all motors are operating at their full speed.

Slow-Speed Motors

It is not difficult to design for this service either slow-speed direct-connected motors or moderate speed motors with herring-bone gear reductions. Either type of motor is satisfactory and it is simply a matter of capitalizing the higher maintenance and increased space requirements of the moderate-speed geared motor as against the slightly higher first cost of the slow-speed direct-connected motor.

VARIOUS APPLICATIONS OF THE PHOTOELECTRIC CELL WITH AMPLIFIER TO PHOTOMETRY

At the Montreal meeting of the American Physical Society, February 26-27, Doctor Clayton H. Sharp presented a paper entitled "Various Applications of the Photoelectric Cell with Amplifier to Photometry" of which the following are excerpts:

A.—An arrangement whereby a photoelectric cell with a vacuum tube amplifier supplants the ordinary photometer head in making a photometric balance has been described before the Illuminating Engineering Society in September 1925. A rotating glass disk, one-half of which is silvered, throws in alternation the light of the "X" lamp and the light of the comparison lamp on to the photoelectric cell, the cathode surface of which is connected to the grid of an amplifying tube. If the two lamps differ in their effect on the cell, variations in the plate current are produced which act through a transformer and through a rectifying device upon a d-c. galvanometer.

B.—Spectrophotometry.

The filament of an incandescent lamp is focussed on a spectrometer slit, the beam passing through a variable sector. The photoelectric cell with amplifier is the detector. A circuit connection is used such that the galvanometer shows only the changes in the plate current. Spectrophotometric measurements of transmission are made by noting the deflection of the galvanometer when the filter is interposed in the beam, and then by means of the sector bringing the galvanometer to the same deflection when the filter has been removed.

C.—Temperature of Lamps.

The ratio of light transmitted by a blue filter to that transmitted by an amber filter as shown by the photoelectric cell varies with the temperature of the source of light. The temperature of incandescent bodies can thereby be determined, using a calibration curve.

The Use of Vibration Instruments on Electrical Machinery

BY J. ORMONDROYD[1]

Non-member

***Synopsis.**—Several mechanical vibration instruments are described and actual problems which these instruments have helped to solve are mentioned. The theory of the seismographic instruments is developed to show the relation between the record or indication and the motion being measured. The limitations in the accuracy of amplitudes recorded or indicated are brought out.*

Introduction

VIBRATION problems in the shop have frequently been left to the care of "penny balancers," men whose practical judgment was not tempered by any accurate knowledge of the vibration properties of bodies or the possible causes of vibration. Their opinions were based on data gathered by the unaided senses of touch, sight and sound. The effects of vibration on the senses of touch and hearing depend on amplitude and frequency together; and it is well known that the eye exaggerates any vibratory motion it observes. Subjective data almost always fail in accuracy. Knowledge is useful only when it becomes quantitative. The question "How much" must be answered explicitly or implicitly before any action can be undertaken.

In any vibration problem there are five things which should be known:

1. Frequency of vibration.
2. Amplitude of vibration.
3. Type of vibration—simple-harmonic or complex.
4. The elastic properties and mass distribution of the vibrating body.
5. A general knowledge of the possible mechanical and electrical forces acting on the body.

The first three must be gotten by quantitative measurement. Observations of these three without measurement is usually valueless. The fourth is gotten from a knowledge of the materials and dimensions of the body. The fifth involves a clear understanding of the mechanical and electrical functioning of the body. This usually must go beyond the knowledge used to design the body since that knowledge, generally speaking, does not take into account the possibilities of vibration. No instrument can supply four and five. Trained human intelligence is necessary here.

It is proposed to show that this problem can be studied quantitatively in the shop and field. The theory and use of a few instruments suitable for this study will be taken up. Only mechanical instruments will be discussed. While electrical methods for measuring vibrations are well known the inconveniences attending the use of the oscillograph have always discouraged any extended application of these methods on machines in production and in operation. Mechanical instruments have the following advantages over electrical vibration measuring devices which depend on the use of an oscillograph:

1. They are easily portable.
2. They can be applied to the job quickly, easily and cheaply.
3. The record or indication is available for immediate use.
4. The record or indication can be taken over a long period of time.
5. No complicated electric circuits are needed.

It should be stated, however, that electrical circuits can be devised to give space-, velocity- and acceleration-time effects; while mechanical instruments are limited to space-time effects. Very high frequencies demand the use of electrical methods.

The theory and practise of five instruments will be given.

Indicating Instruments.

1. The vibrating reed.
2. The vibration amplitude indicator.

Recording Instruments.

3. The directly connected vibrograph.
4. The vibrograph.
5. The torsiograph.

The vibration amplitude meter as described in the paper was developed by engineers of the Westinghouse Company; although forms of this meter can be bought on the market. The other devices are commercial instruments widely used in Europe and slowly coming to the attention of American engineers. The use of each instrument is illustrated in the following pages by concrete examples.

The theory of the instruments is given in the appendices. Mechanical vibration-measuring instruments as they now stand cannot be used safely unless their limitations are clearly appreciated. The relationship between the record or indication and the actual motion is not a simple one. Knowledge of the theory of this relationship must be considered a necessary tool to the man who uses the instruments.

Linear Vibrations

Most of the vibrations in electrical machinery are linear in nature. Four of the five instruments dis-

1. Motor Engineering Department, Westinghouse Electric & Manufacturing Company.

Abridgement of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies available upon request.

cussed are for the study of linear vibrations. In general, the fields of application of these four instruments are:

1. The vibrating reed—for measuring frequency only.
2. The amplitude meter—for measuring amplitudes only.
3. The seismic vibrograph—used where a complete analysis of the motion is desired. Applicable where the instrument cannot be attached to a fixed reference point.
4. The directly connected vibrograph—used where a complete analysis is wanted. Applicable where the instrument can be attached to some fixed reference point.

Measuring Frequencies—the Vibrating Reed

The properties of resonance in a thin cantilever beam have long been used in turbo generator tachometers and electrical frequency meters. Fig. 1 shows a reed which can be varied in length and which can be attached to

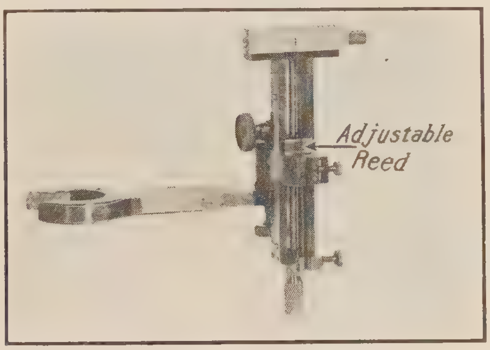

Fig. 1—Reed Vibrometer

any vibrating body. The body should have a weight considerably larger than the weight of the instrument, say ten times as great, to preclude the possibility of the instrument affecting the motion of the vibrating body.

The instrument shown in Fig. 1 consists of a claw to be clamped under a bolt head, two joints rotatable at right angles to each other, a main frame bearing a reed length scale on the side, an amplitude scale across the top and a long screw. A clamp carriage rides on the main frame; its position being adjusted by the screw. The reed is held tightly in a fixed clamp at the bottom of the frame and its free length is varied by the position of the movable clamp on the carriage.

The instrument is bolted to the vibrating machine and the free length of the reed is adjusted until the largest amplitude of motion is obtained at the end of the reed. This is read on the transverse scale. The instrument then is in resonance with the impressed frequency. This frequency can be determined by measuring the free length of the reed.

This device is so highly selective (damping forces extremely small) that it can be used only on vibrations with almost absolutely constant frequency. The least variation in frequency near the resonant point will give very large fluctuation in amplitude. This limits the instrument to uses on turbo generators and to cases where the cause of the vibration lies in magnetic pulls or in torque pulsations. These latter have frequencies depending on the voltage frequency of the line which varies slightly.

Given the same frequency, the amplitudes can be compared. Turbo generator balancing can be controlled by the use of a reed under these conditions.

A knowledge of the frequency of a vibration will often point to its cause. Unfortunately, the vibrating reed is too sensitive to be generally used for this purpose; since in most cases the frequencies vary enough to spoil the accurate setting of the reed.

The Measurement of Amplitudes Only—Amplitude Meter

In many cases the frequency of vibration is known and the magnitude of its amplitude is of importance. Here the amplitude meter is a handy tool. This instrument consists of a mass suspended from a frame by a spring. (See Fig. 12.) The frame is held against or attached to the vibrating body. The relative motion between the spring-suspended mass and the frame is equal to the total range of the vibratory motion when the frequency of the motion is above a certain value. This relative motion is transmitted through levers to an indicator which makes a band image over a calibrated scale.

The most important use for the instrument is in field balancing of turbo generators. The instrument is attached to the bearing pedestal and four amplitude readings are taken—one with the original unbalance; the other three with an arbitrary unbalance applied successively in three different points of the balancing plane. The amplitude readings determine a system of vectors which give the amount and direction of the original unbalance. This rational procedure saves time and is more accurate than the old cut-and-try methods.

In cases where periodic forces have set stators of electrical machines in vibration, the amplitude meter has been used to determine the nodes or points at which the stator motion amplitude was zero. A check on the number and position of the nodes, along with a measurement of the frequency, indicates the curative measures to be taken. It also indicates the accuracy of design calculations.

The comparative roughness of commutators can be gaged with a small amplitude meter by holding it on the brushes. Where a definite minimum roughness is permissible on a given line of motors, this is a simple means of inspection.

Where large numbers of any one motor have to be made with a given minimum of vibration, the amplitude meter again serves as a means of objective inspection.

Application of the Seismic Vibrograph

The seismic vibrograph is shown in Fig. 2. It consists of a heavy pendulum suspended between two springs. (See Fig. 13.) The pendulum is placed at right angles to the direction of the motion to be measured. The frame of the instrument is attached to the vibrating body and moves with it. The spring-borne pendulum stands still in space when the frequency of motion is above a certain value and the relative motion between the frame and the pendulum bob is transmitted through a system of levers to a recording pen. A strip of paper actuated by clockwork moves under the pen and a record of the motion shows as a wave on the paper. A timing device records equal time

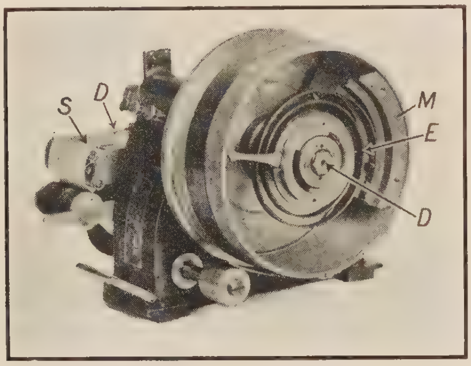

Fig. 2—Seismic Vibrograph

intervals on the same strip. The record can be analyzed for frequency, amplitude and type of motion.

The seismic vibrograph finds its chief application in the measurement of floor vibrations in buildings and electric locomotives. The absence of any fixed reference point in cases like these necessitates the use of a seismic instrument.

Although the cause of troublesome vibrations on factory floors or office buildings usually can be traced to its source without the help of instruments, there are cases where the cause is entirely elusive until vibration measurements are made. This is true where many pieces of rotating apparatus exist near together. A vibrograph record will show the frequency of the strongest vibration and this knowledge will usually point to the cause.

A common cure for floor vibration is mounting the machine which causes the disturbance on cork pads or springs. The design of a flexible mounting is determined by the weight of the machine and the frequency of the disturbance which it causes.[2] It is entirely possible to design a flexible mounting in such a manner that the transmitted vibrations become worse instead of better. In a rational design of flexible mounting the vibrograph supplies the necessary data on frequencies.

In gas or Diesel Electric Locomotives the floor vibrations may come from many sources. Unbalance in the reciprocating parts of the prime mover or in the rotating parts of the engine, generator and numerous auxiliaries—any one of these may be causing the objectionable disturbance. Usually they must all run simultaneously so no successive elimination of causes is possible. Another source of noticeable linear vibrations may be the periodic twist in the common foundation of the generator and engine due to the inherently varying torque of the prime mover. A vibrograph record usually shows up the troublesome frequency and leads to the proper remedy. This remedy may consist in the correcting of a bad unbalance, the changing of frame work structure to avoid local resonance, or the avoidance of resonance in the entire cab-spring system.

Application of the Directly Connected Vibrograph

Fig. 3 shows a side view of this instrument and Fig. 16 shows a top view. The instrument is clamped tightly to a body assumed to be absolutely stationary. A light rod transmits the motion from the vibrating body (See Fig. 16) to a bell crank which magnifies the motion and actuates the pen-push rod. The pen system, paper drive and timing device are all the same as on the seismic vibrograph (See Fig. 16).

The entire region close to a vibrating machine is often vibrating with the machine. In cases where this is so bad that the assumption of a stationary reference point cannot be approached even approximately special mountings for the instrument must be used. In power houses a heavy weight—a ton or more

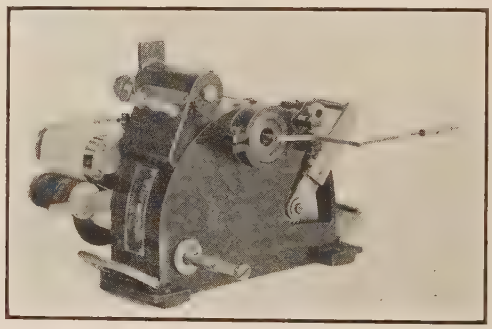

Fig. 3—Directly Connected Vibrograph

—is suspended from the crane and the instrument is mounted on the weight (See Fig. 4). On the test floor a heavy mass mounted on springs has been used. In both cases a seismic system is formed, having a low natural frequency which does not respond to the small high frequency forces transmitted through the bell crank. Usually the floor vibrations are small enough so that any object near the vibrating machine may be considered stationary enough to serve as a mounting for the instrument.

The Study of Critical Speeds

In rotating apparatus the critical speeds are the most important objects of vibration study. Existing methods

2. See C. R. Soderberg, *Elec. Journal*, Vol. XXI, 1924, p. 160.

of balancing rotors are accurate enough to eliminate violent vibrations at any speeds except those in the region of the critical speeds. The directly connected vibrograph finds its most extensive use in the study of the critical speeds of structures and machines.

Experimental Determination of Natural Frequencies

Any structure which is deformed by the application of external forces will return to its natural conformation, when these forces are removed, assuming deformations within the elastic limit of the structure. If the applied force is in the form of a blow the return to the position of static equilibrium is made through damped oscillations having the natural frequency of the structure. This fact is used in determining the natural frequencies of bodies too complicated in shape to be calculated. The body is clamped in its natural position, a blow is struck and the vibrograph records the ensuing damped oscillation.

Fig. 4—Vibrograph for Powerhouse

The calculation of the natural frequency of turbo generator field structure is complicated by the presence of field winding slots. A method of calculating this frequency was devised analytically and checked experimentally by means of the vibrograph. The mass of the generator rotor is too large to be affected by a blow; so the principle of resonance was used. A small d. c. motor with a badly unbalanced rotor was mounted on the top center of the large rotor which was held in pedestals mounted on the test floor. The vibrograph was mounted below the center of the field. The motor speed was varied until the amplitudes of vibration of the whole field became a maximum. A curve of the amplitudes read from the records indicated the critical speed very distinctly and a check between theory and practise was possible.

Effects of Structural Parts on Critical Speeds

Perhaps the most valuable service which the directly connected vibrograph has performed has been in the emphasizing of the tremendous differences which can exist between the critical speed in rotating apparatus, as calculated on the rotor alone and the actual critical speed of the completed and installed machine. When a draftsman in the ordinary course of design calculates the critical speed of his rotor he tacitly assumes that the bearings in which it will rotate are held rigidly fixed in space and that his calculated critical speed will be the critical speed of the completed machine. But the action of the bearing under the influence of unbalanced forces depends on the flexibilities of the pedestals, bed-plate and ultimate foundation. These additional flexibilities, usually neglected, all tend to make the actual critical speed lower than the calculated speed.[3] This fact is of importance since all small and medium sized machines are usually built to run below their calculated critical speeds.

The effects of parts of the structure external to the rotor shaft may range all the way from complete control of the actual critical speed (as in the case of all modern balancing machines, where the flexibility connected to the vibrating bed determines the frequency of the system) to the case where the bearing is in extremely rigid pedestals attached to an extremely rigid foundation. In this latter case the critical speed as calculated would be the actual critical speed in service.

An extensive series of tests were run by Dr. S. Timoshenko and Mr. L. S. Jacobsen on an experimental synchronous condensor to prove that the effects of structural flexibilities could be predetermined accurately. The machine was rated 5000 kv-a. at 750 rev. per min. They tried three shafts of different diameters and two different bed-plates—all other conditions remaining constant. Bed-Plate B was 40 per cent heavier and twice as stiff as Bed-Plate A (See Table I). The results are shown in Table I.

TABLE I

			Bed-plate A		Bed-plate B	
Direction of Vibration	Diameter of Shaft	Critical Rev. per min. Calculated on Rotor Alone	Actual Critical Rev. per min. No Field Excitation	Per Cent Lower	Actual Critical Rev. per min. No Field Excitation	Per Cent Lower
Horizontal	10.5 in.	1270	1050	17%	1110	12.5%
	12.5 in.	1470	1180	20%	1270	13.5%
	15.5 in.	1820	1325	27%	1460	20.5%
Vertical	10.5 in.	1270	1010	21%	1110	12.5%
	12.5 in.	1470	1130	23%	1280	13. %
	15.5 in.	1820	1220	33%	1410	22.5%

Another interesting case was an experimental elevator motor generator set consisting of two standard d-c. machines, the rotors of which were on a common shaft and the stators being mounted separately on a common bed plate. The critical speed calculated on the rotor alone was about 3200 rev. per min. The actual critical speed was found to be at 1850 rev. per min. due to the combined additional flexibility of the feet and bed-plate. The system in reality was one with several degrees of freedom instead of one. By tying the two stators together with a brace, the feet flexibilities were elimin-

3. See C. R. Soderberg, *Elec. Journal*, Vol. XXI, No. 12, p. 579.

ated and the critical speed became 2800 rev. per min. (See Fig. 5.) When the inboard holding down bolts of one of the machines in the unbraced set were loosened only half of the foot material of that machine was acting as a restraint on its motion. This increase of foot flexibility lowered the critical speed to 950 rev. per min.

It can be seen that errors of critical speed calculation in the order of 40 per cent are possible in the ordinary course of design. This becomes important in case the designer thinks that he is running not far below the critical speed as he calculates it in the ordinary way.

Effects of Foundation. Synchronous machines have been tested on the test floor and in the field which showed a difference of 12 per cent. in the critical speed on account of the differences in foundations under the bed-plate. And in turbo generators, mounted as they are in power houses, several critical speeds are passed through in going up to the running speed some of which are due to flexibilities in the foundation itself. This problem is one of extreme difficulty and it is being studied by means of the vibrograph.

Effect of Magnetic Pull. Unbalanced magnetic pull also lowers the critical speed.[4] A mechanical spring always tends to return to its position of equilibrium

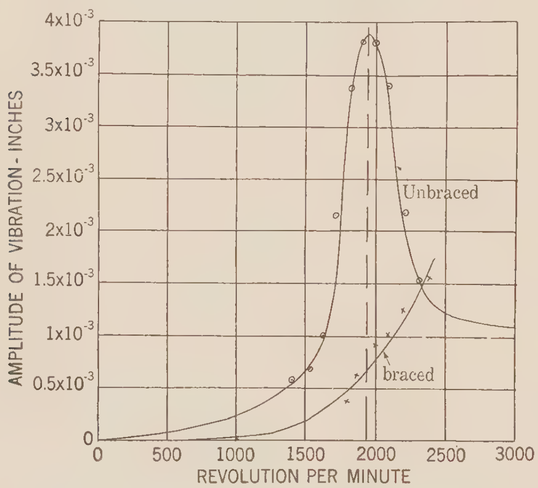

Fig. 5—Amplitude Curve—Rev. per Min. M. G. Set Vibration of Experimental M. G. Set with and without Brace

when stretched or compressed. A body in between the poles of a magnet is pulled away from its equilibrium position more and more, the farther it gets from the position of equilibrium. An unbalanced magnetic pull has a negative spring effect which decreases the total spring constant of the whole system.[5] For a given machine this can be calculated. For a certain field excitation, it reaches a maximum effect, for stronger fields its effect falls off again. In the case of the synchronous condenser mentioned before the maximum effect was at 30 amperes, field current. Table II shows the effects at this maximum taken from vibrograph records.

TABLE II

Direction of Vibration	Shaft Dia.	Bed-Plate A: Critical R.P.M No. Field	Bed-Plate A: Critical R.P.M 30 Amperes	Bed-Plate A: Per Cent Lower	Bed-Plate B: Critical R.P.M. No. Field	Bed-Plate B: Critical R.P.M. 30 Amperes	Bed-Plate B: Per Cent Lower
Horizontal	10.5	1050	930	11.5	1110	994	10.5
	12.5	1180	1070	9.0	1270	1165	8.0
	15.5	1325	1230	7.0	1460	1375	6.0
Vertical	10.5	1010	883	12.5	1110	994	10.5
	12.5	1130	1015	10.0	1280	1175	8.0
	15.5	1220	1120	8.0	1410	1320	6.0

Vibrations not due to Critical Speeds

Noisy and violent vibrations cannot always be attributed to critical speeds. The case of an induction regulator standard for single-phase 60-cycles, but applied and rated for 25 cycles shows this very clearly. The machine was noisy on the test floor, due to impact between the segment teeth and the worm. The diagnosis of critical speed in resonance with the single-phase torque was made and the usual remedy of changing the shaft diameter was tried, but without diminishing the noise. The vibrograph was mounted to measure the tangential motion of the regulator gear segment. The supply frequency was varied and the kv-a. was kept constant. The resultant torsional vibration amplitude plotted from the records are shown in Fig. 6. Instead of resonance at 25-cycle voltage (50-cycle torque variation) the amplitudes tend

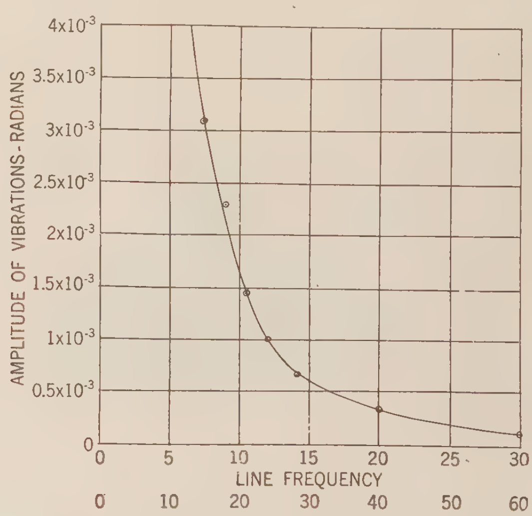

Fig. 6—Amplitude-Frequency Curve—Induction Regulator Vibration Frequency Cycles per Second

to increase toward infinity at zero frequency—or to some extremely low frequency resonance amplitude due to the clearances in the worm and segment system.

The rotor was acting very similarly to a rotor free to rotate in bearings acted upon by a periodic torque.

The amplitude of torsional vibration of such a body is in general

$$\theta_0 = - \frac{\phi_0}{I \omega^2}$$

4. Rosenberg, Trans. A. I. E. E., 1918, p. 1425.
5. C. R. Soderberg, *Elec. Jour.*, Vol. XXI, No. 12, p. 582.

θ_0 = amplitude of torsional motion
ϕ_0 = amplitude of applied torque (proportional to the kv-a. in this case.)
I = the moment of inertia of rotor
ω = $4\,\pi \times$ line voltage frequency

The only fundamental way to limit the oscillation was shown to be by the application of a fly-wheel to increase the inertia of the rotor. Since this could not be done gracefully or conveniently (and the idea of a fly-wheel on an induction regulator being revolutionary to say the least) the noise was cut out by putting longitudinal flexibility in the worm and making the segment from a non-metallic material. This decreased the deceleration value of the impact and completely eliminated the trouble.

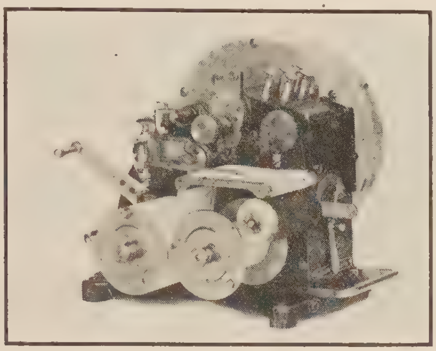

Fig. 7—Torsiograph

The direct connected vibrograph has been used extensively in field balancing and in the study of magnetic noises due to stator vibrations.

Torsional Vibrations

Torsional vibrations although of common occurrence cannot be observed very readily even when they are of destructive magnitude. These small periodic angles of lead and lag superimposed on the constant advance of rotating parts are only noticeable when they cause chattering in gear teeth or give rise to linear vibrations on the foundation due to stator reactions. Most shaft and coupling breakage can be attributed to the dynamical stresses induced by unnoticed torsional vibrations. Where torsional critical speeds occur these stresses become very large. Although it is much easier to calculate torsional critical speeds than linear critical speeds, very few designers check this important point. Torsional vibrations being hidden are ignored.

The torsiograph has an important educational mission in emphasizing the existence of these oscillations in a concrete way. Its chief uses are in the study of torsional critical speeds, in the location of the causes of vibration and in the checking of design theories.

The torsiograph consists of a light pulley and a fly-wheel mounted concentrically on the same axis. (See Figs. 7 and 8.) The fly-wheel is held in a definite static relationship to the pulley by means of two opposing springs. (See Fig. 14.) Relative motion between the pulley and the fly-wheel about this position of equilibrium is possible. The relative motion actuates a system of bell cranks which move a recording pen push rod. The recording-paper drive and timing device are exactly the same as for the vibrograph. In addition to the timer there is a pen actuated by a solenoid which is excited by the making of a contact once every revolution of the body being tested. This indicates the instantaneous angular position of the body.

The pulley is belted to the shaft to be tested and follows its motions. The fly-wheel tends to rotate at a uniform average speed for frequencies above a certain value. The relative motion between the irregularly moving pulley and the steadily moving fly-wheel produces the record.

Torsional Vibrations due to Mechanical Causes

Gear vibrations have been studied with the torsiograph—the most interesting conclusion drawn being that torsional vibration with a steady tooth contact frequency only occur when the gears are heavily loaded. This points to the fact that any dynamical theory of gearing must take into account the effects of deflections in the gear structure (the only thing that changes with load) as well as geometrical errors in tooth form and spacing.

Gas Electric Drive Vibrations

The torque delivered by an internal combustion engine is inherently irregular, consisting of a constant average torque with a periodically varying torque superimposed. The relationship between the magnitudes of these two torques depends on the number of cylinders and the number of strokes per combustion cycle. The fundamental of the periodic torque has the firing frequency and all other higher harmonics also exist. The mechanical system consisting of generator rotor, fly-wheel and crankshaft with its attached reciprocating masses, has many natural frequencies. Theoretically the combination of the harmonics of the variable torque and the many natural frequencies of the rotational system lead to an infinite number of possible critical rev. per min. of the generating unit. Practically resonance with the fundamental and perhaps the second harmonic have given the im-

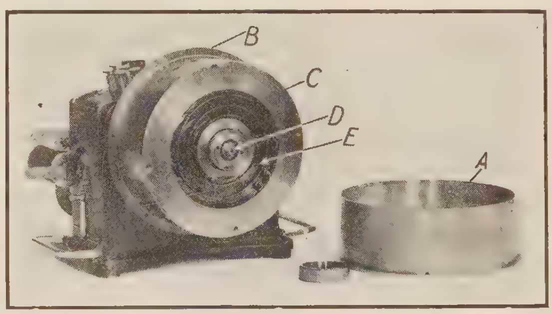

Fig. 8—Torsiograph

portant critical speeds. The other harmonics are usually too small to produce noticeable effects.

Several gas electric generating units have been investigated by means of the torsiograph—the critical speeds determined and operating speed limits have been established. The theories for precalculating the critical speeds have been checked experimentally by means of the instrument.

Where flexible couplings have been used on gas electric units records on both sides of the coupling have shown how the coupling acts as a wave filter, only the lowest harmonic of the variable torque being prominent on the generator side of the coupling and at speeds far above the lowest critical speed of the rotational system even the fundamental gets very small.

Torsional Oscillations In Side-Rod Electric Locomotives

The torsional oscillation of the rotating system of a side rod electric locomotive is an important problem where locomotive frames, rods and cab structure are very light as in European practise. In the heavier American designs this problem loses much of its importance; but the careful designer attempts to make the possibilities of destructive torsional vibrations remote. The torsiograph has been used extensively in Europe in checking the numerous theories which have been developed on this subject. Theoretically, errors in side rod length (or "tram") errors in crank length and quarter, and pin clearances, can give rise to oscillation having driver rotational frequency, and the second and fourth harmonic of this frequency. Torsiograph records show that these exist; but the presence of large damping forces (especially where flexible gears and pinions are used) keeps the amplitude of these oscillations within safe limits even at the critical speeds. An experimental check can be made on design theories devised to lessen the possibilities of destructive action.

Where gears are interposed between the motors and drivers, resonance with the tooth frequency vibrations must be avoided on all parts of the motors and locomotive frame near the motor bearings. The torsiograph records show what conditions of load are necessary to bring about large amplitude of these gear frequency oscillations.

Torsional Vibration from Electrical Causes

It is a well-known fact that single-phase rotating machines vibrate torsionally with double line-voltage frequency[6] and amplitudes proportional to the kv-a. The reaction of these single-phase torques through the stators of large machines have made it advisable in some cases to go to special spring mounting to protect the foundation of the machine from the double-line frequency forces.[7] The torsiograph makes a very convenient means of studying these oscillations.

It is generally assumed that polyphase motors rotate uniformly under all conditions. Torsiograph records in many instances show double line frequency torsional oscillation just as in the case of single-phase machines—the amplitudes being much smaller. Experimentally this was shown to be due to unbalance in the primary winding—unbalanced voltage or unbalanced impedance being equally effective. It can be shown theoretically by the use of symmetrical coordinates,[8] that the positive and negative sequence currents and voltage due to electrical unbalance produce a small torque of double line frequency superimposed on the average constant torque expected. The amplitude of the resultant vibrations is proportional to the amount of unbalance. Similarly it has been shown theoretically and experimentally that unbalanced resistances in the secondary of a wound rotor motor can produce destructive torsional vibrations on the rotor[9].

Unbalance in the secondary currents which have a fundamental frequency equal to the slip frequency will induce currents in the primary circuit having a frequency of $f - (n + 1)\, s$ where

f = line frequency

n = number of unbalanced secondary harmonic

s = slip frequency

Torques produced by a current having a frequency $f - (n + 1)\, s$ and a flux with frequency f will be of two frequencies $2f - (n + 1)\, s$ and $(n + 1)\, s$.

This theory was developed by C. R. Soderberg and tested by him by means of the torsiograph and oscillograph.

In tying any a-c. motor onto a common shaft bearing other rotating masses the designer must be careful to avoid resonance with double the line frequency of the a-c. supply. This is especially necessary if the motor is single-phase; but should not be neglected even in the case of polyphase motors.

6. A. L. Kimball and P. L. Alger, Trans. A. I. E. E., 1924 p. 730.

7. C. R. Soderberg, *Elec. Journ.*, Vol. XXI, No. 8, p. 383.

8. C. L. Fortescue, Trans. A. I. E. E., 1918, p. 1027.

9. A. F. Kenyon, *Elec. Journ.*, Vol. XXII, No. 9, p. 435.

DIAMOND MINING AT NIGHT

An interesting application of modern electric flood lighting is in the Premier Mine in Transvaal, Africa, where the work of removing diamond-bearing earth is carried on twenty-four hours a day.

The mine extends over some 78 acres and at present has been dug out to a depth of about 500 ft. Excavations of diamond-bearing earth in the volcanic vent where diamonds are usually found are done in a series of terraces of 50-ft. depth. Since the mine has had to be worked day and night, it was necessary to supply efficient illumination. Arc lighting was tried but the blasting proved detrimental to the delicate mechanism of the arc lamps resulting in expensive maintenance. Now, electric flood lights housed in 14 huts are situated on the rim of the mine, with the rays projected from the rim to the working surface at distances ranging from 900 to 1600 ft.

Ionization Studies in Paper-Insulated Cables—I.

BY C. L. DAWES[1]
Member, A. I. E. E.

and

P. L. HOOVER[2]
Associate, A. I. E. E

***Synopsis.**—A research investigation of the ionization phenomena which occur in paper-insulated, high-voltage power cables is being made at the Harvard Engineering School under the auspices of the Impregnated Paper-Insulated Cable Research Committee. The paper presents some of the preliminary results which have been obtained, certain tentative conclusions that are suggested by the data and a description of the method developed for making the measurements. It is a preliminary report and in subsequent papers it is intended to record the progress of the investigation as it proceeds.*

The paper consists essentially of four parts as follows:

(a) A number of curves of power, power factor and capacitance taken on samples of cable at two frequencies and over a wide range of temperature. These curves show well-known characteristics, but in order to exaggerate these effects, cable models were made up to simulate the general conditions in a cable—one model consisting of glass and air only and another of glass, air and paper. Tests of these cable models gave very interesting results, particularly with reference to power factor. They also show rather clearly the baffling action of paper and the effects on power, power factor and capacitance when this baffling action is eliminated. In practically all the curves, the power and power factor begin to increase rapidly at a lower voltage gradient than the capacitance.

(b) Discussion of the results obtained and certain tentative conclusions which may be drawn from the results so far obtained and reported herein.

1. Ionization in the dielectric of an air condenser increases its capacitance slightly at first and then rapidly as the electron is separated from the atom. In our measurements we accordingly found that the power and power factor increase rapidly at a lower voltage gradient than the capacitance.

2. Ionization which occurs within air spaces in a dielectric may be called "restricted ionization" in that the current is limited because of the remainder of the dielectric in series.

3. With "restricted ionization," the voltage across each air space reaches a constant finite value with indefinite increase in the over-all voltage. The resistance of the ionized space, therefore, must be inversely as the current.

4. Consequently when this condition is reached, the ionization loss may be proportional to the charging current.

5. The increase of power factor with increase in voltage gradient with subsequent decrease of power factor is due to the fact that the capacitance of the solid dielectric, which is substantially constant, is in series with ionized air spaces whose resistances are inversely as the current. A simple mathematical analysis of this type of electric circuit shows that power-factor curves should have the form obtained in the measurements. Hence power factor alone is not a criterion of the degree of the completeness of saturation by compound.

6. Ionization by its bombarding action may destroy the baffling action of paper.

7. Ionization may produce potential gradients tangential to the surface of the layers of paper which, in conjunction with the bombarding action, may be the cause of the so-called "tree designs."

(c) Discussion of methods for measurements of this sort and a description of a new type of bridge which was devised for the measurement of dielectric losses at these extremely low power factors with the necessary high degree of accuracy. A large air condenser used as a standard and a vibration galvanometer of unusually high sensitivity and wide range of tuning were designed for use as a detector. The bridge is quickly and accurately balanced by varying a resistance and a mutual inductance. The angle of defect of the standard air condenser, although extremely small, is nevertheless very important in measurements of this character. This angle was measured by a substitution method and corrections made accordingly.

(d) Four appendixes discussing respectively (1) method of measuring defect angle of the standard air condenser, (2) mathematical analysis of a condenser of composite dielectric consisting of air and solid homogeneous material, (3) measurement of the high-voltage ratio, and (4) measurements of the capacitance, and other electrical constants of an ionized air space in series with a solid dielectric.

Introduction

THIS paper presents some of the results of research work being carried on at the Harvard Engineering School on the subject of Ionization Phenomena in the Insulation of High-Voltage Paper Cables. The work is conducted under the auspices of the Cable Research Committee, which is a subcommittee of the appropriate committees of the National Electric Light Association, the American Institute of Electrical Engineers, and the Association of Edison Illuminating Companies. The National Electric Light Association provides the Research Fellow for the work. The work is under the immediate supervision of a Cable Research Committee made up of members of the Faculty of the Harvard Engineering School, and one of the authors is Chairman of this Committee.

A summary of the more important results which have been obtained up to the present time is presented together with suggested explanations based upon the modern theory of ionization. However, an important object in presenting these results at this time is to invite discussion, from which it is hoped to obtain ideas which will aid in the further prosecution of the investigation.

Procedure

The fact that ionization or breakdown of occluded air and other gaseous films exists in laminated insulation, such as impregnated paper as used in cables, has been known for some time. However, opinions and theories differ as to the exact nature of this ionization and its effects on the insulation of the cable as a whole. A fundamental object of our investigation is to determine, so far as possible, the exact nature of these ionization phenomena and to suggest in explanation a rationa

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theory which can be substantiated by experimental data.

Naturally, our first procedure was to obtain experimental data on samples of commercial cables under various conditions of temperature, of frequency and of voltage gradient. From the analysis of these data it was hoped that some of the laws of the ionization taking place within the cables could be determined and a theory suggested to account for them.

In order to study such laws it is necessary to make measurements with a degree of precision much higher than is required for commercial testing. To obtain high precision in measuring such losses is not easy, especially at the present time when cables are designed particularly to have low dielectric loss and low power factor. Accordingly, before beginning the work, it was necessary to devise a satisfactory method of making the measurements. The authors investigated the various methods which have been described up to the present time and tried many of them. However, they were all found to be unsatisfactory because of their lack of precision or the difficulty in manipulation. After considerable experimenting, during which two or three promising methods were discarded, the one shown in the diagram of Fig. 1 was found to be the most satisfactory as regards accuracy, simplicity and ease of manipulation.

A simplified diagram of the bridge is given in Fig. 2. Referring to Fig. 1, the cable and a resistance R_2 of the order of 50 to 100 ohms for a 10 ft. length of cable, form one side of the bridge, while a standard air condenser C_1 and a resistance R_1 of the order of 1000 ohms form the other side. The primary of a mutual inductance M is inserted in series with the cable. The galvanometer G is connected in series with the secondary of the mutual inductance between points c d of the bridge. The voltage drops across R_1 and R_2 are small, being of the order of one volt, so that no difficulty is experienced from the effects of the capacitance to ground of the detector. A simplified diagram of this bridge is given in Fig. 2. The cable is represented by the capacitance, C_2, and its equivalent series resistance, r_2. The standard air condenser is represented by the capacitance, C_1, and its equivalent series resistance is shown as r_1.

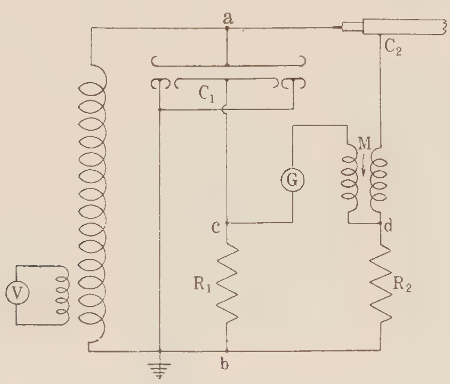

FIG. 1

The self-inductance L of the primary of the mutual inductance M is approximately 10 millihenrys, so that its impedance is small compared with that of the cable. Hence, in developing the equations for this bridge, the impedance of the primary of the mutual inductance M is neglected. In the equations for the bridge, let

$$\eta_1 = (R_1 + r_1)\, C_1\, \omega = \operatorname{Tan} \psi_1$$
$$\eta_2 = (R_2 + r_2)\, C_2\, \omega = \operatorname{Tan} \psi_2$$

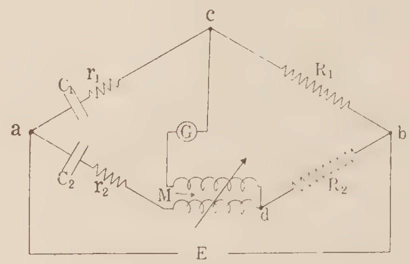

FIG. 2

A simple calculation gives for the conditions of balance:

$$C_1\, R_1 = C_2\, R_2\, \frac{(\eta_1^2 + 1)}{(\eta_1\, \eta_2 + 1)} \tag{1}$$

and

$$\frac{M\, \omega}{R_2} = \frac{\eta_2 - \eta_1}{\eta_1\, \eta_2 + 1} \tag{2}$$

Since η_1 and η_2 are small compared to unity, the second order terms may be neglected and

$$C_1\, R_1 = C_2\, R_2 \tag{3}$$

and

$$\operatorname{Tan} \psi_2 - \operatorname{Tan} \psi_1 = \frac{M\, \omega}{R_2}$$

or

$$\operatorname{Tan} \psi_2 = \frac{M\, \omega}{R_2} + \operatorname{Tan} \psi_1 \tag{4}$$

If the condenser C_1 is a perfect air condenser, $\operatorname{Tan} \psi_1 = 0$, and ψ_2 is the angle of phase defect of the cable. If ψ_1 is not zero, the correction is simple.

Careful check measurements showed that our air condenser, although carefully insulated and guarded, did not have a phase angle of 90 deg. After considerable difficulty, the authors were able to obtain this angle at the lower voltages by a substitution method which is described in Appendix I. It was not possible for the writers to determine the angle at the higher voltages as they did not have a high voltage air condenser whose loss would remain constant when its capacitance was varied.

The bridge was balanced by varying R_1 and M, R_2 remaining constant. If the air condenser be assumed perfect.

$$\operatorname{Tan} \psi_2 = \frac{M\, \omega}{R_2} = \sin \psi_2$$

The power factor of the cable = cosine θ = sin ψ_2 which is sensibly equal to tan $\psi_2 = \frac{M\,\omega}{R_2}$, since ψ_2 is a small angle. Hence, for approximate work with the higher power factors the mutual inductance may be calibrated directly in power factor for any given frequency. This is a distinct advantage both in research work and in routine testing.

Considerable difficulty was experienced in obtaining a suitable detector. The detector must not only be sensitive but must have moderately high impedance in order to work properly with the bridge. The various standard types of vibration galvanometer were tried, but none was found satisfactory. Therefore, it became necessary to design and construct one. The moving iron-vane type, having an electromagnet for excitation, was found to be the most satisfactory.

With low voltages, or with small samples, the detector itself would not give the desired sensitivity. We, therefore, designed and constructed a three-stage resistance-coupled vacuum tube amplifier, which increases the sensitivity by something like 1000 times.[4]

With the foregoing apparatus it is possible to balance the bridge to measure phase angles to 0.001 per cent and detect even smaller changes. In view of the fact that the dielectric properties of the insulation which were measured are not constant, the foregoing precision is much greater than is necessary.

The voltage was measured by means of a voltmeter coil in the high-voltage winding of the 100-kv., 15 kv-a., 60-cycle transformer which supplied the power. The multiplying factor of the voltmeter coil was determined by a null method described in Appendix III.

The standard condenser consisted of two polished copper plates with rounded edges and corners. The low-voltage plate is guarded as is indicated in Fig. 1. The area of the working plate is 4 ft. × 5 ft. (1.219 m. × 1.525 m.). The distance between plates can be adjusted to suit the voltage, hence constant sensitivity is obtained.

The capacitance C_1 of the standard condenser was measured with a precision capacitance bridge. Knowing this capacitance and the resistance R_1, the capacitance C_2 of the cable is determined. It is then a simple matter to calculate the power, since the power

$$P = E^2\,C_2\,\omega \sin \psi_2$$

where ψ_2 is the angle of phase-defect of the cable. If ψ_2 is small, the power

$$P = \frac{E^2\,C_2\,M\,\omega^2}{R_2}$$

A 15-kv-a., 220-volt, 60-cycle alternator known to have a reasonably good sine wave[5] was used in all these measurements. Its voltage was controlled with a motor-driven field rheostat.

Measurements. Measurements were made at first on single-conductor cables having walls of insulation of approximately 20/32 in. thickness (16 mm.). Such cables would ordinarily be rated at 33 kv. Fig. 3 shows a typical power-factor curve obtained with a 500,000-cir. mils. cable having this thickness of wall. We noticed that at 50 kv. the rate of increase of the power factor became less. This has been observed by others[6]. At 60 kv. it apparently reached a maximum and then decreased slightly. This decrease of power factor in high-voltage cables after a maximum is reached has been known for some time among engineers.[7] So far as we know, however, no satisfactory explanation has been given for this character of power-factor curve. In fact, this decrease in power factor appeared to be contrary to the well-known explanations heretofore given to account for the increasing power factor

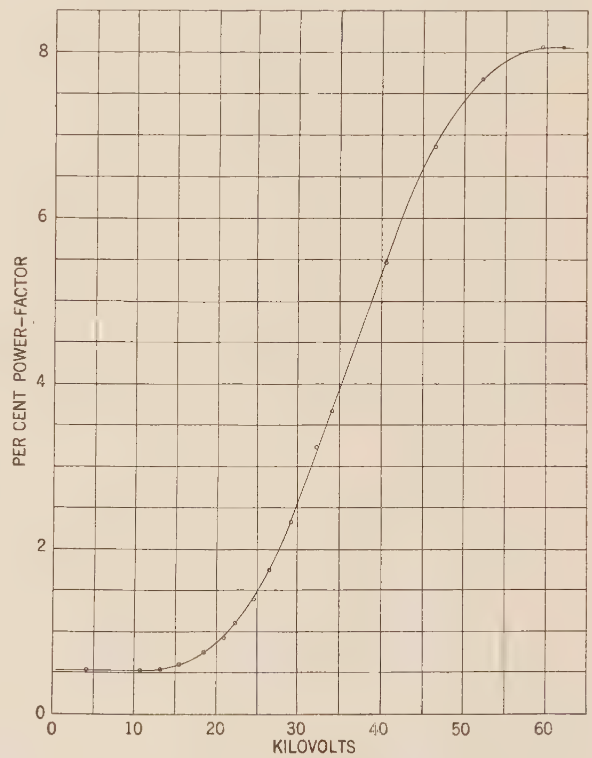

FIG. 3—5,000,000-CIR. MILS, SINGLE CONDUCTOR CABLE

20/32 inch insulation. 1/8-inch lead
20 deg. cent. 60 cycles per second

4. See TRANS. A. I. E. E., 1925, p. 122, Discussion by C. L. Dawes.

5. For an oscillogram of this voltage wave, see "Artificial Transmission Lines," Kennelly & Lieberknecht, TRANS. A. I. E. E., Vol. XXXI, 1912, p. 1138.

6. C. F. Proos. "Some Considerations on the Dielectric Losses in High-Tension Cables." Report to Ass. of Managers of Electrical Works in the Netherlands, 1921. (Proos plotted P/E^2, or equivalent conductance, against voltage which gives the same character of curves as power factor against voltage, provided the capacitance of the cable does not change very much.)

7. D. W. Roper. TRANS. A. I. E. E., 1925, p. 116. Curve *E*, Fig. 4. Also *Electric World*, Feb. 21, 1925, p. 399.

with increasing potential gradient. That is, the ionization commences in the air spaces adjacent to the conductors and occurs progressively in the air spaces from the center outwards as the potential is raised. In view of these uncertainties, it appeared to us that further study of this phenomenon might give some additional information as to the nature and effects of ionization in cables.

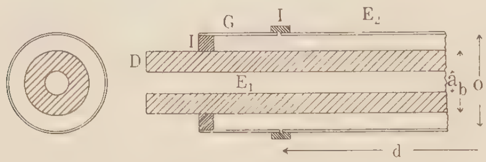

FIG. 4

- E_1 Mercury electrode
- E_2 Brass tube
- I Bakelite rings
- G Guard Rings
- D Glass tube
- a 3.1 mm.
- b 9.3 mm.
- c 14.3 mm.
- d 31.5 cm.

Schrader[8] also found with small air spaces in flat dielectrics that the power factor increased to a maximum and then decreased to a low value with increase of voltage.

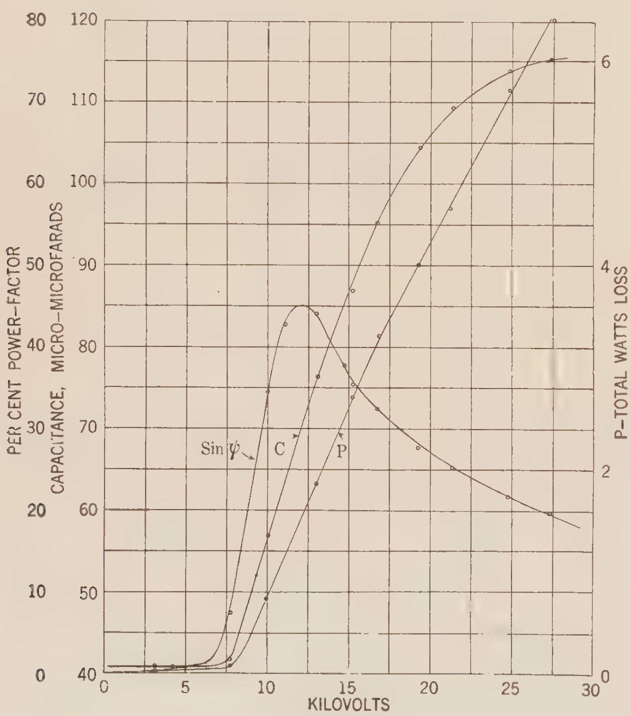

FIG. 5—CABLE MODEL. GLASS-AIR DIELECTRIC

20 deg. cent. 60 cycles per second

For purposes of study, we made a small cable model, Fig. 4 in which the ionization effects occurring in actual cables would be exaggerated. A glass tube having an inside diameter of 3.1 mm. and an outside diameter of 9.3 mm. was filled with mercury, the mercury forming the center electrode. A brass tube having an inside diameter of 14.3 mm. was placed concentric with this glass tube and insulated from it. The length of the brass tube between guard rings was 31.5 cm. Fig. 5 shows the curves of power factor, capacitance and watts loss obtained with this cable model at room temperature and at a frequency of 60 cycles per second. This is the character of curves which we expected the cables would have.

In order that we might obtain sufficiently high voltage gradients in cables to produce similar effects, it was found desirable to use smaller cable. Accordingly, a 00 A. w. g. (diameter = 0.418 in. = 10.6 mm.) single-conductor cable with a 9/32 in. (7.1 mm.) wall of insulation was used. In accordance with ordinary

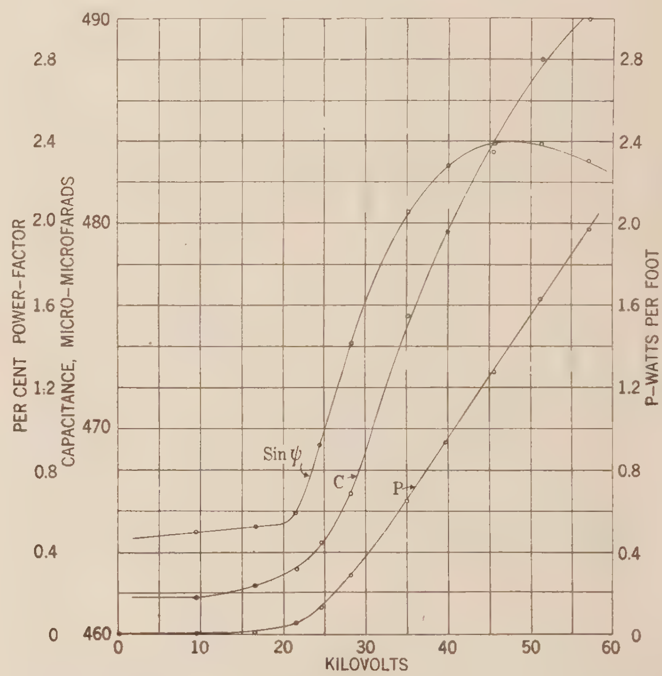

FIG. 6—IMPREGNATED PAPER CABLE. NO. 00 SINGLE CONDUCTOR

9/32-inch insulation. 20.4 deg. cent. 60 cycles per second

American practise, this cable would probably operate at 12 kv. The cable was guarded at its ends and end-bells filled with impregnating compound were fastened to the ends to prevent the compound from oozing out and air entering with change in temperature. The net length of cable tested was 7½ ft. (2.3 m.). Curves taken for this cable under various conditions are shown in Figs. 6 to 10 inclusive.

In Fig. 6, curves of power factor, capacitance and watts per foot are given for a frequency of 60 cycles per second and at a temperature of 20.4 deg. cent. as shown. At each reading sufficient time was allowed for the reading to become constant. It will be noted that the power factor after reaching a maximum value of 2.4 per cent actually does begin to decrease, as had been anticipated.

8. Schrader. "Corona in Air Spaces in a Dielectric." TRANS. A. I. E. E., Vol. 41, 1922, p. 583.

The difficulties in obtaining quantitative data on cable samples under these conditions of test are illustrated in Fig. 7, which shows curves taken at a frequency of 60 cycles per second and at a temperature of 53.8 deg. cent. The potential was first increased as before, readings being taken at frequent voltage intervals, and only after conditions had apparently become constant. When 58 kv. was reached the potential was decreased and readings taken at inter-

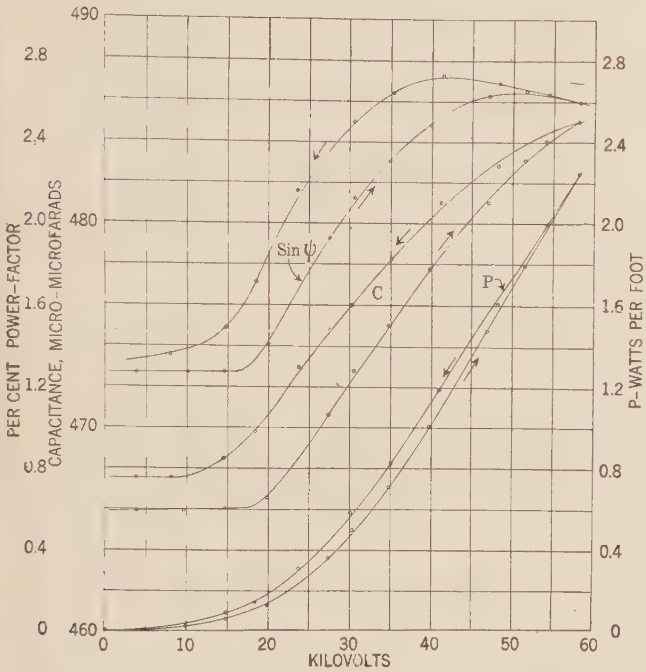

FIG. 7—IMPREGNATED PAPER CABLE. NO. 00 SINGLE CONDUCTOR

9/32-inch insulation. 53.8 deg. cent. 60 cycles per second

vals to zero voltage. These readings, however, were taken immediately following each adjustment of voltage, a pause of only two or three minutes being necessary for taking each reading. Hence the dielectric was not given time to attain constant condition. It will be noted that the values of power factor, watts per foot and capacitance are all considerably greater for decreasing voltage than for increasing voltage. It should also be noted that with increasing voltage the watt curve and the power-factor curve begin to increase at a considerably lower voltage than the capacitance curve. Moreover, with decreasing voltage the curves reach constant values at lower values of voltage than they do with increasing voltage. Before taking each reading with decreasing voltage, if sufficient time for conditions to become constant be allowed, the values obtained are in most cases only slightly greater than the corresponding results with increasing voltage. In some instances, however, it has been found even when steady conditions are reached that the values with decreasing voltage are less than corresponding values for increasing voltage. We have also found that measurements vary considerably from time to time, even when taken under the same conditions. With impregnated paper insulation, for example, dielectric measurements frequently do not repeat themselves. On one occasion after completing a 60-cycle test, we found that the 25-cycle losses were greater than the 60-cycle losses even though sufficient time had been allowed for the cable to reach constant conditions. Due to such variations in the cable dielectric, great care must be taken if quantitative data are to be of value.

In Fig. 8 the solid lines are the curves of power factor and capacitance taken at 60 cycles but at a temperature of 88 deg. cent. It will be noted that the power factor increases rapidly when the potential is increased from 2 to 8.5 kv., at which point it reaches a first maximum. It then decreases, reaching a minimum at 15 kv. and again increases in the ordinary manner. This peculiar effect cannot be due to errors in measurement, since this portion of the curve was checked carefully. Moreover, this effect occurs only at high temperatures. It appears again in Fig. 9 taken at a temperature of

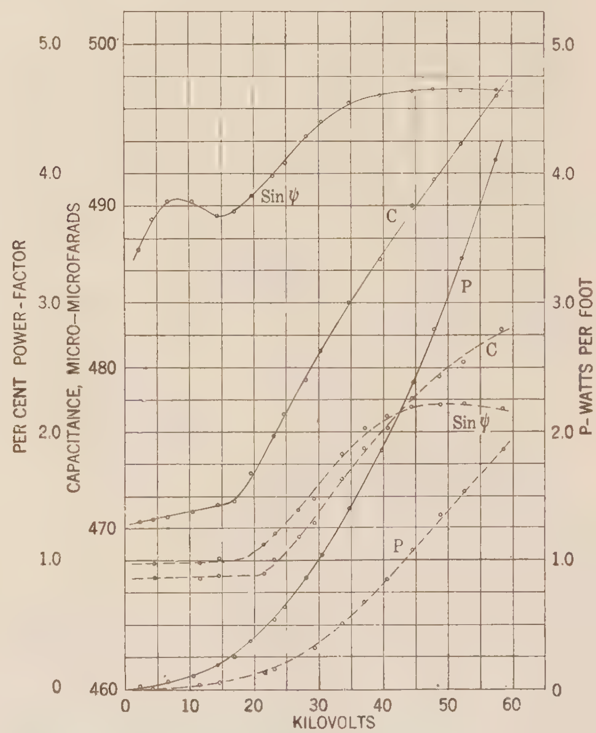

FIG. 8 —IMPREGNATED PAPER CABLE. NO. 00 SINGLE CONDUCTOR

9/32-inch insulation. 60 cycles per second. 88 deg. cent. (Dotted curves are Fig. 10)

98.5 deg. cent. and at a frequency of 32 cycles per second. The authors are not prepared at this time to offer a definite explanation of this sudden variation in the power factor.

It will be observed at the higher temperatures that the range of maximum power factor is greater than at lower temperatures; also the power factor does not begin to decrease at as low a voltage as it does at the

lower temperatures, and further the decrease in power factor is not so marked.

In Fig. 9 the solid lines are curves taken at a frequency of 32 cycles per second and a temperature of 98.5 deg. cent. It will be observed that this power-factor curve has the same peculiar characteristic which appears in the 60-cycle curve, Fig. 8.

Fig. 10 shows a set of curves in which the watts per foot are plotted as a function of temperature, each curve being taken at a constant voltage. The frequency throughout is 60 cycles per second.

Analysis of Ionization Phenomena

Since the curves taken with our glass-tube cable model (Fig. 5) have all the dielectric characteristics

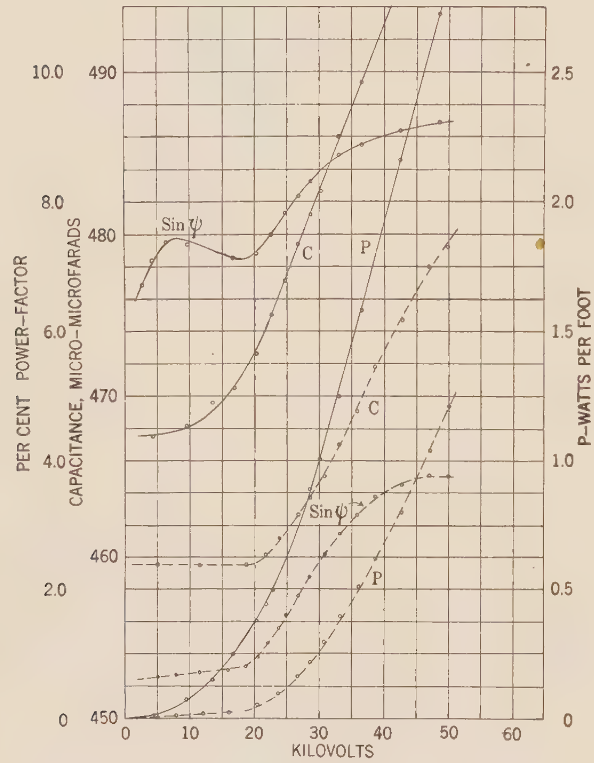

Fig. 9—Impregnated Paper Cable. No. 00 Single Conductor

9/32-inch insulation. 32 cycles per second. 98.5 deg. cent. (Dotted curves are Fig. 12)

of the actual cable, it seemed as if further data taken with such models might be of considerable assistance in the analysis of cable phenomena, particularly in view of the fact that the composite dielectric of glass and air is much simpler than that of paper, a compound of low viscosity, and air. Accordingly, another model similar to that of Fig. 4 was made and curves taken, Fig. 11. The glass of this model was slightly different from that of the first model, the curves for which are shown in Fig. 5. Aside from slight quantitative differences, these curves are similar to those of Fig. 5.

In attempting to analyze our own results, as well as those of Schrader, we found it necessary to know the effect of corona formation on the voltage gradient in air spaces and on the capacitance of air spaces. With the formation of corona about cylindrical conductors,

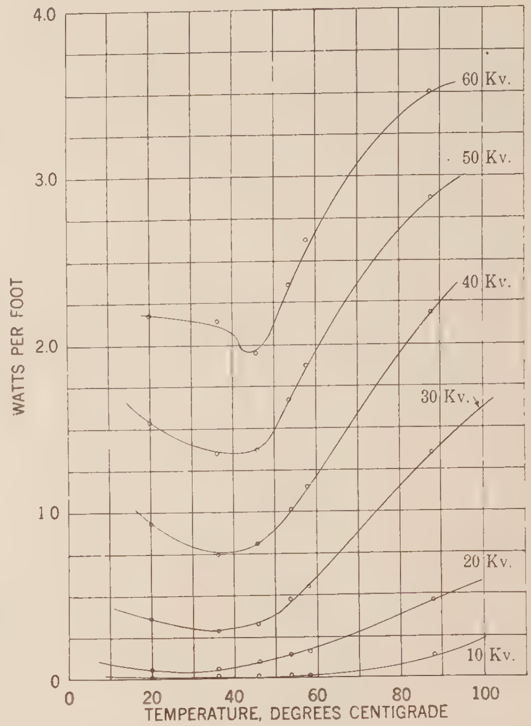

Fig. 10—Impregnated Paper Cable. No. 00 Single Conductor

9/32-inch insulation. 60 cycles per second

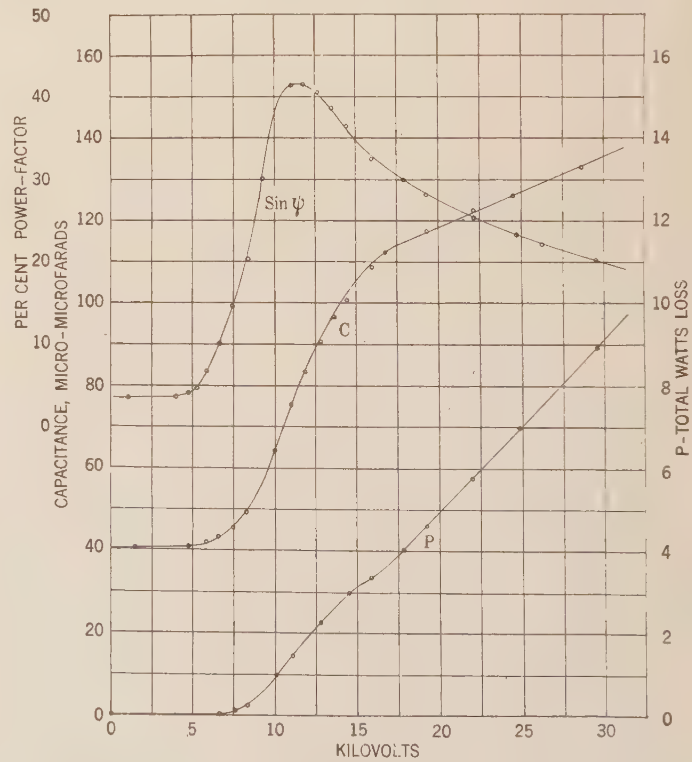

Fig. 11—Cable Model. Glass-Air Dielectric

20 deg. cent. 60 cycles per second

it has frequently been assumed that corona increases the effective diameter of the electrode[10]. This may

be true, but certainly this assumption must be qualified to the extent that this corona formation is not equivalent to increasing the diameter of the electrode in the sense that the voltage across the corona formation is negligible. Peek[10], later in his book, recognizes this fact for on page 85 he states: "Hence, corona seems to be either in *effect* a 'series resistance,' or it grades or distributes the flux density."

If, for example, in a composite dielectric of solid material and air, the voltage across the air spaces were neglected after corona is formed, the capacitance would increase abruptly at the critical gradient and immediately attain a nearly constant value. With our glass cable models, the capacitance should behave in almost this same manner when the gradient is sufficient to cause corona throughout the air space between the glass tube and brass cylinder. A study of Figs. 5 and 11 shows that this is not true.

So far as is known, no attempt has been made to determine the law connecting change in capacitance and ionization. Accordingly, some preliminary investigations of this phenomenon have been made by the authors and some of the results are given in Appendix IV. These results show that with a flat air space 2 mm. thick the capacitance of the air space when ionized reaches a value which is 28 times the capacitance for the non-ionized condition.

In addition to the increase in capacitance in the air films, when ionization takes place, the relation of voltage gradient to current also changes. To show in more detail the effects of this relationship, a reproduction of some curves given on page 267 of Townsend's "Electricity in Gases," is shown in Fig. 12. These curves show the current-voltage relation of air with parallel plate electrodes. The curves are taken for spacings of 2, 1, and 0.5 cm. The pressure in each case was 1.1 mm. of mercury and the initial ionization was produced by X-rays. These curves represent some of the first data taken in experimental work on ionization phenomena and are now considered quite elementary. Nevertheless, they are important in that they appear to offer explanations of some of the ionization phenomena which we have observed.

At low voltages, a current which, although very small, is finite flows through the air space. This current is due to the motion of the free ions and is practically independent of the voltage. In air, under ordinary conditions, this so-called "saturation current" is very small, and is practically negligible.

With increasing voltage the velocity of the moving ions increase and ionization by collision begins. As a result, the current increases rapidly, but there is no discontinuity in the curve. The curves have sharp bends, however, and after a certain voltage gradient is reached, the current density increases so rapidly with slight increases in voltage that we usually regard these curves as discontinuous and consider that the air has a definite breakdown gradient. It is important to remember that although the curves are not discontinuous with voltage gradients beyond the bend, the current density increases enormously with further slight increase in gradient. In the limit the current density becomes so great that sparkover or arc discharge results and the curve then takes a negative slope. With air films in solid dielectrics, the current is restricted by the solid dielectric in series with the air film, and the discharge does not go beyond the glow or corona formation, unless rupture of the entire dielectric occurs.[12]

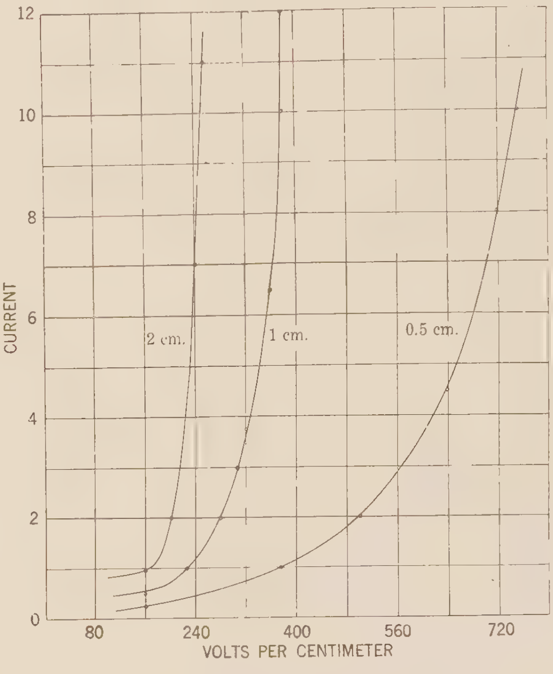

FIG. 12—CURRENT-VOLTAGE CURVES FOR AIR. PARALLEL ELECTRODES

1.1 mm. Hg. (Data from Townsend "Electricity in Gasses," page 267.)

From the curves, Fig. 12 it is apparent that for each spacing of electrodes the voltage gradient *increases* with the ionization current density until a limiting voltage gradient, which cannot be exceeded, is reached. With the 2 cm. spacing, Fig. 12 this gradient is approximately 180 volts per cm. and with the 1 cm. spacing it is approximately 300 volts per cm. With air, under ordinary conditions of temperature and pressure, this gradient is 30 kv. per cm. (maximum), except with very thin films.[13] With any current whose

10. F. W. Peek, Jr., "Dielectric Phenomena in High-Voltage Engineering," p. 27.

M. F., Gardner, "Corona Investigations on an Artificial Line," JOUR. A. I. E. E., Aug. 1925, p. 813.

J. J. Ryan, and H. H. Henline, "The Hysteresis Character of Corona Formation," JOUR. A. I. E. E., Sept. 1924, p. 826. (The statement, however, is omitted in the "TRANSACTIONS.")

12. A. L. Atherton, "1922 Developments in Autovalve Lightning Arresters," TRANS. A. I. E. E., Vol. XLII, (1923) p. 179.

13. F. Dubsky, "The Dielectric Strength of Air Films Entrapped in Solid Insulation," TRANS. A. I. E. E., Vol. XXXVIII, 1919, p. 537.

magnitude is consistent with values of currents existing in dielectrics, such as are given in Fig. 12, the voltage gradient in the air is never zero. On the contrary, the gradient increases with increasing current density, approaching a definite maximum gradient for that particular air film. These effects have been verified by the tests made on ionized air, the results of which are given in Appendix IV.

Returning now to the cable models, let e_1 be the potential across the air dielectric, and e_2 the potential across the glass dielectric. Until the ionization voltage is reached, the potentials e_1 and e_2 will be inversely proportional to the normal capacitances c_1 and c_2 of the air and glass. Beyond this voltage, however, the potential e_1 cannot increase appreciably but must remain substantially constant. Hence, any further increase in the total voltage must be taken by the capacitance c_2. Curves illustrating this effect are given in Fig. 13, in which the voltages e_1 and e_2 are plotted as functions of the total voltage E. Each of the voltages e_1 and e_2 increases proportionately to E until 7.5 kv. is reached, beyond which point e_1 remains constant. For voltages greater than this critical voltage, any increase in E produces in equal increase in e_2. This assumes that e_1 and e_2 are substantially in phase. This is not strictly true, particularly at large values of E, as e_1 tends to come in phase with the current because of ionization losses in the air space. This would only change the slope of e_2 without changing its general character.

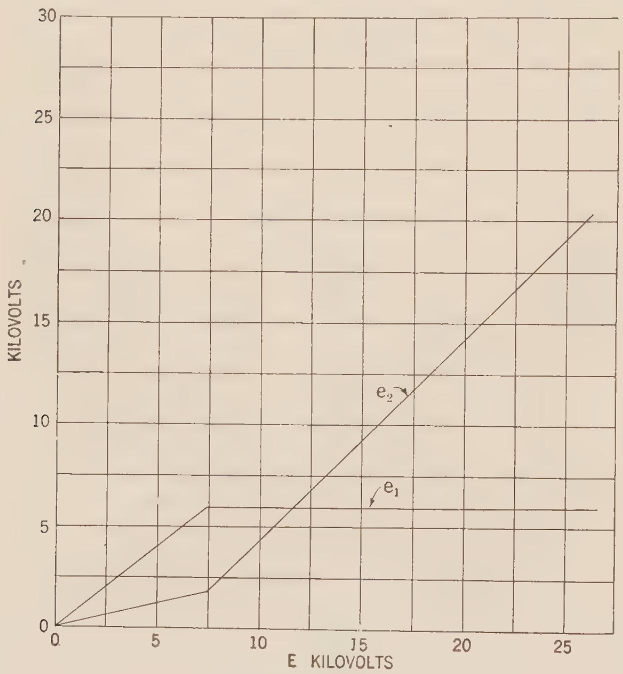

FIG. 13—VARIATION OF e_1 WITH TOTAL VOLTAGE, E

It seems reasonable, therefore, to conclude that corona in gaseous films produces a definite limiting gradient in the film, which depends on the nature of the gas, the pressure, the temperature and the geometry of the film. The current density in such an ionized gas does not depend on the voltage across the film, but rather on the impressed voltage and the remainder of the dielectric circuit. That is, the solid or non-ionized dielectric will limit the current density and it cannot increase indefinitely, as is indicated by the curves of Fig. 12 until rupture of the entire dielectric occurs.

This gives a condition which may be considered as *restricted ionization.*

Decreasing Power Factor. Schrader,[8] in explaining the decreasing power-factor with increasing voltage, which he obtained, states that it "indicates that saturation of ionization is approached." Our ordinary understanding of the statement "saturation of ionization" is that practically all the molecules have become ionized and the resulting ions and electrons are acting as carriers of electricity across the gaseous film. Calculation shows that this condition cannot exist in such air films. For example, if it be assumed that there is but one electron per molecule carrying the ionization current, the current density through the ionized gas would be several amperes per sq. cm. Obviously, no such current density is possible in air films within dielectrics.

Proos[6] plotted conductance against kilovolts and obtained curves very similar to power-factor curves. but consisting of three straight lines.

Clark and Shanklin[9] plotted "specific resistivity (effective)" or P/E^2, or the equivalent shunt resistance of the cable, against kilovolts. (This is the reciprocal of the quantity which Proos plotted.) They explain the lesser rate of decrease of their curves as follows:

> "Gradually a point of saturation is reached and the energy consumed by ionization approaches more nearly a true ohmic loss."

Shanklin and Matson[14] explain similar characteristics as follows:

> "Complete saturation is not yet reached, but the curve is flattening out, showing that the majority of the gas spaces have been ionized."

Although these statements are in a sense correct, we do not feel that they are adequate explanations of the phenomena. Even though ionization is a contributing cause, the character of these curves is not determined solely by the degree of ionization, but rather by the changes, due to ionization, in the constants of the series condensers consisting of the solid dielectric and the air films.

The equivalent circuit of the solid dielectric and air space is shown in Fig. 14, in which c_1 is the capacitance of the air space and r_1 is its equivalent shunted resistance; c_2 is the capacitance of the solid dielectric and r_2 is its equivalent shunted resistance. It can be shown

14. Shanklin and Matson, "Ionization of Occluded Gases in High-Tension Insulation," TRANS. A. I. E. E., Vol. XXXVIII, 1919, p. 489—See page 494.

that the sine of the angle of phase defect of the combination is

$$\sin \psi = \frac{e_2 \sin \psi_2 + e_1 \sqrt{1 - \dfrac{(e_1 c_1)^2}{(e_2 c_2)^2}}}{E} \qquad (5)$$

where e_1 and e_2 are the voltages across c_1 and c_2, E is the total voltage and ψ_2 is the angle of phase-defect of the solid dielectric. (See Appendix II.)

Below the ionization voltage, $e_1 c_1 = e_2 c_2$ since e_1 and e_2 are substantially in phase with each other, hence the radical is equal to zero and the power factor equals

$$\sin \psi = \frac{e_2 \sin \psi_2}{E}.$$

Above the ionization voltage, e_1 and c_2 remain nearly constant. c_1 and e_2 both increase very rapidly (Fig. 13.) From our experimental data with both the cable models and with flat air spaces (Appendix IV) we know that immediately above the ionization voltage e_2 increases more rapidly than c_1. Hence, the expression under the radical sign increases rapidly, which causes a rapid increase in sine ψ or in the power factor of the combination. Also, when ionization commences, the left-hand term becomes small in comparison with the right-hand term. At higher values of the voltage E, c_1 commences to increase very rapidly also, and the rate of increase of the right-hand expression becomes less than the rate of increase in E. As a result, with further increase in E. sin ψ and hence the power factor of the combination commences to decrease. Therefore, above the ionization voltage, sin ψ at first increases rapidly, reaches a maximum and then decreases.

We realize that in a cable the air films are not all ionized simultaneously, but the films nearest the conductor probably ionize first, due to the higher gradient there, and a greater and greater number further from the conductor become ionized as the voltage is increased. Hence, the power factor is determined by the summation of the effects of the separate films. This results in power-factor curves which rise less rapidly and which have more gradual changes in slope, as is shown by comparing the curves taken with actual cables with those of model cables.

Determining as closely as possible the constants of our glass cable models, we have calculated the power factor for the model whose curves are shown in Fig. 5 using the foregoing equation. We assumed that the ionization voltage began at a definite value of 7.5 kv. In Fig. 15 the experimental curve and the calculated curve are plotted. In our opinion, the agreement between the curves is unusually good, particularly for dielectric phenomena of this character. These curves show that the foregoing theories are correct not only in a qualitative sense, but substantially so in a quantitative sense as well. They also show that the decreasing power factor is not caused by such phenomena as saturation of ionization but is merely the natural result of a combination of series capacitances, of this character. We conclude from this that when ionization exists in cables the power factor alone cannot be used to determine the degree of ionization in any one cable or to compare the ionization characteristics of different cables.

It is apparent that it is possible to calculate with a fair degree of precision the effects which may be expected in solid and gaseous dielectrics, provided we know the constants of the solid medium and the constants of the gaseous films.

It has been recognized for some time past that, although the paper itself has lower dielectric strength than the impregnating compound, the dielectric strength of the cable is increased by using paper in combination with the compound. This is probably

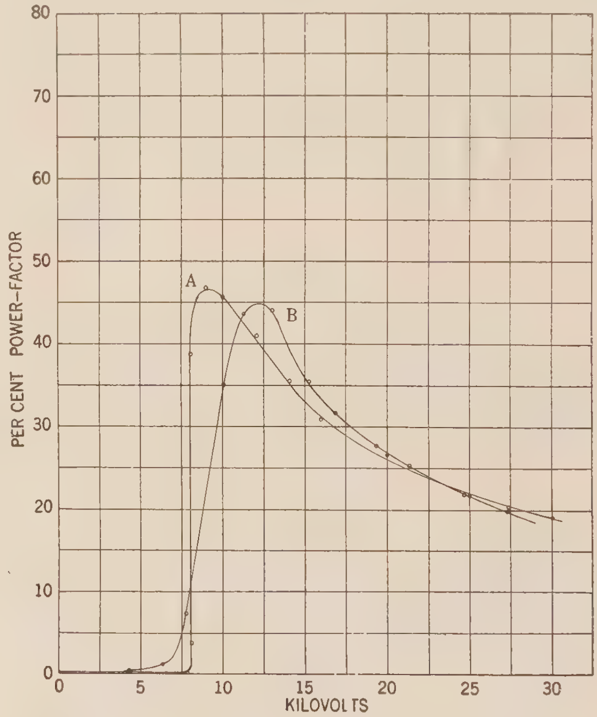

Fig. 15—Cable Model. Glass-Air Dielectric

A. Calculated
B. Experimental

due to a considerable extent to the fact that the paper acts as a barrier,[15] which prevents or restricts the motion of the ions through the insulation. We felt it worth while to study these effects with our cable models. The glass tube of the model whose characteristics are shown in Fig. 11 was wrapped tightly with dry manila paper, such as is used for insulating cables. The brass tube was then slid over the paper. Thus we produced a cable model having a composite insulation of glass, air and paper.

Fig. 16 shows the curves of power factor, watts loss and capacitance plotted with kilovolts which we obtained with this model cable. The ionization point

15. William A. Del Mar, Electric Cables, p. 84.

started at a lower voltage than with air and glass alone as the dielectric. This would be expected. The power factor increased to a first maximum of 24 per cent at 7 kv. When the voltage was increased above 7 kv. the power factor decreased to a minimum of 18 per cent at 16 kv., after which it increased again to a second maximum of 27.5 per cent at 22 kv. Beyond this the power factor continued to decrease, reaching at 32.5 kv. nearly a constant value. The capacitance curve increases steadily with increased kilovolts, but shows changes in slopes corresponding to the maxima and minima of the power-factor curve. The watts loss curve begins to increase with the first increase of power factor and then increases suddenly when the power-factor curve begins to increase for the second time at 16 kv.

Fig. 16 indicates that this composite cable has a second ionization voltage. The paper was removed and examined, and found to be pierced throughout by numerous fine pinholes. This effect could not be found unless the voltage were carried up beyond the second ionization voltage. The explanation of the second ionization voltage is now obvious.

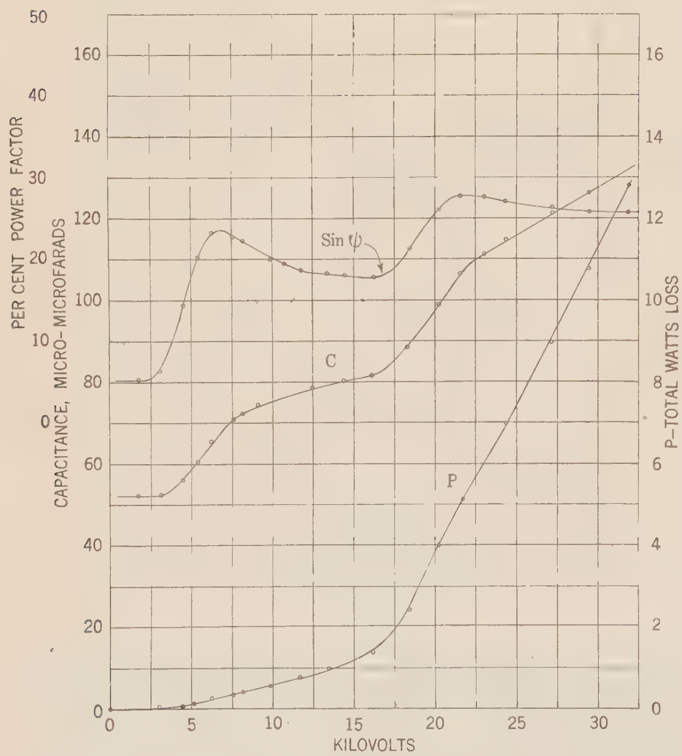

Fig. 16—Cable Model. Glass-Air-Paper Dielectric
20 deg. cent. 60 cycles per second

As the impressed voltage is increased, the voltage across the air spaces reaches its maximum value and does not increase further. Hence the gradient in the paper and the gradient in the glass increase more rapidly with further increase in impressed voltage. When the gradient in the paper becomes sufficiently high, the ions striking its surface are drawn through causing perforations. A number of ions concentrating at one point causes a pinhole. The restricted ionization current density prevents dynamic rupture. Because of the perforations, the dielectric and the barrier actions of the paper are in part destroyed. Any increase in impressed voltage now occurs almost entirely across the glass tube and the power factor begins to increase and then decrease again in the manner which was discussed in connection with Figs. 5 and 11.

This suggests that one of the requisite qualities of paper which is to be used for cable insulation may be its barrier action under conditions similar to the foregoing.

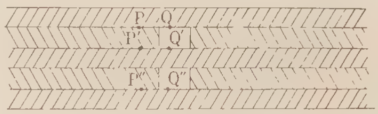

Fig. 17

The foregoing experiments and the resulting analyses suggest hypotheses which may explain the origin of "tree designs" and the incipient causes of breakdown. Fig. 17 shows a magnified and perhaps exaggerated section of paper insulation in which two spaces, one on each side of a paper tape, happen to occur directly opposite each other, due to the tapes not touching. Owing to the fact that the tapes do not quite touch and the compound does not quite fill all the voids so formed, gas films exist in spaces Q' Q and Q' Q''. At low voltages, below the ionization voltage, the potential gradient across the air films and the corresponding layer of paper will be equal in most cases. Hence no potential difference will exist between points P and Q, P' and Q', P'' and Q''. Above the ionization voltage the gradient through the paper increases. The gradient through the air-spaces cannot increase beyond a limiting value as already demonstrated. This causes a potential difference to exist between points P and Q, P' and Q', P'' and Q''. Therefore, there will be voltage gradients tangential to the surfaces of the paper which may cause creepage or tangential currents which carbonize the surfaces and ultimately result in "tree designs." This creepage may be followed by discharges over the edges of the tape, and these discharges are likely to be more or less oscillating in character and of high frequency. These discharges cause further local heating and further destruction of insulation. The barrier action of the paper at Q' may also be destroyed, as with the authors' paper-glass models, causing increase in the watts loss (Fig. 16), and ultimately producing hot spots. Hence, these effects are all cumulative, and eventually rupture will occur at this point.

Conclusions

1. When corona occurs in air spaces, the increase in energy loss begins at a lower voltage gradient than the increase in capacitance.

2. With ionization in a gas, the voltage gradient must always be greater than zero.

3. The gradient in an ionized gaseous dielectric is finite but cannot exceed a definite maximum value. This maximum value is the breakdown gradient for each particular condition.

4. The ionization current is limited or restricted by the solid dielectric.

5. When the voltage gradient in cables has reached a value sufficiently high to ionize all the gas films in the dielectric, the ionization loss becomes proportional to the cable charging current.

6. The power factor is a direct function of the relative capacitance of the solid dielectric and air spaces in series. Hence, power factor of itself does not show the degree of ionization which exists in a cable.

7. The power factor due to a combined solid and ionized gaseous dielectric can be calculated if the constants of the two dielectrics are known.

8. Restricted ionization effect has been called "the barrier action of paper" in high-voltage cables and a method is suggested whereby it can be measured and the relative quality of cable papers be determined.

9. "Tree designs" are probably due to tangential gradients set up in the cable as a direct result of ionization.

10. Ionization causes progressive deterioration due to the high-frequency oscillations accompanying these internal discharges. The increased local temperatures or hot spots, due to ionization, tend to exaggerate these effects.

The authors are indebted to the members of the electrical engineering staff of the Harvard Engineering School for their cooperation in this research and particularly to Professor H. E. Clifford for his suggestions in the preparation of the paper.

Abridgment of Paper on Concluding Study of Ventilation of Turbo Alternators Multiple Path Radial System

BY C. J. FECHHEIMER[1] and G. W. PENNEY[1]

***Synopsis.**—In 1924 two papers were presented before the A. I. E. E. on Turbo Alternator Ventilation. In one of the papers tests on two models for two methods of ventilation were described, and data from the tests were given. The other paper contained a mathematical treatment for one system of ventilation, which was based upon the data obtained from the tests. It was recognized that the tests were not sufficiently accurate to evaluate the loss coefficients, nor was it possible to obtain data on the distribution of volumes for the intake vents. For that system, (see Fig. 1), it was found that the influence of rotation upon total volumes and their distribution could be neglected; consequently the investigation could be continued on stationary models. Those tests, the methods of determining the losses and the equations derived therefrom are given in this paper.*

Since the effect of rotation could be neglected, the test could be reduced to a model which represented only one axial row of vent ducts. On this model the stator vent ducts were imitated by square brass tubes with a plaster of paris restriction cast in one end to imitate the vent duct restriction so that the pressure drop obtained for either direction of flow was approximately the same as in a stator vent. A long steel channel or duct represented the section of the air-gap. Some of these brass tubes, representing intake vents, lead from a large sheet metal box to the gap channel. Other tubes, representing discharge vents, lead from the gap channel to the atmosphere. The gap channels could be inter-changed readily to represent various sizes of air-gaps. Any desired number of intake and discharge tubes could be used so as to represent any desired layout of the machine.

The volumes in individual intake tubes were measured by reading on a manometer the drop in pressure from the intake chamber to a point a little ways down the tube. For the discharge tubes small impact tubes were employed. Each tube was carefully calibrated before making any other tests; a thermal volume meter was used for calibrating an orifice, and the orifice was used for the tube calibrations. Various difficulties arose, and the means of overcoming them are given.

Tests were made with a group of intake vents, and the losses were separated into (1) those in the tubes; (2) those accompanying a right angle turn; (3) those due to a stream of one velocity impinging upon a stream of another velocity; (4) those due to sudden increase in velocity; (5) those due to surface frictions. Similar tests on the discharge side showed that the losses there could be separated into (1) those in the tubes; (2) those accompanying a right angle turn; (3) those due to sudden decrease in velocity; (4) those due to surface friction.

The losses were put, for the most part, into comparatively simple expressions. They were then combined in order to obtain final solutions. There was no difficulty on the intake side in obtaining a differential equation which admitted of ready integration. On the discharge side, however, it was necessary to use approximations. With the aid of the final equations the total volumes and their distribution can be calculated for a given pressure drop. One difficulty is that the equations include trigonometric and hyperbolic functions of quantities involving the distance between the point where the gap velocity is maximum to the points where the gap velocity is zero. The latter point, called the "balance point" is not known, and a simultaneous solution of the transcendental equations needed for its determination, is impossible. Suggestions for a direct simple approximate solution are given, which may be followed by trial and error methods. In most of the applications, only one or two trials were required.

The equations were checked for accuracy by comparison with tests made on the tubes, on the turbo model of 1922 and 1923, and with those on an actual machine. The agreement in total volumes was very close, and is considered to be quite good for distribution also.

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1. Both of the Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies upon request.

Introduction and Purpose

At the 1924 Midwinter Convention of the American Institute of Electrical Engineers, two companion papers were presented on the general subject of Ventilation of Turbo Alternators[2]. One dealt with a description of two models on which the experiments were made, the methods of conducting tests, together with representative data and the important conclusions. The other paper (by D. Bratt) was mathematical, the equations being derived from an ideal system, in which all losses in the air-gap were neglected; he increased the losses empirically on the discharge side, so that the measured and calculated total pressure drops agreed. Bratt's equations applied to the system of ventilation in which the air flows axially in the air-gap, shown schematically in Fig. 1. That system was the one adopted by the Westinghouse Company, as tests on the turbo models indicated its superiority over the other system in which the air flows circumferentially in the air-gap.

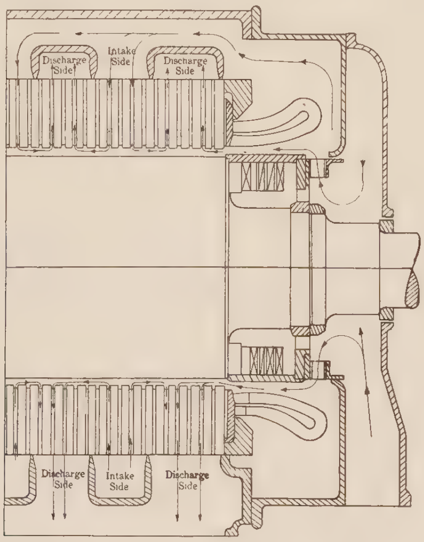

Fig. 1—Scheme of Ventilation of Turbo Alternator

The experimental data obtained from the large wooden models were too inaccurate to enable an evaluation to be made of the losses of head at the turns and other parts of the air circuit so as to incorporate them in the equations. Furthermore, no method was then, or is now, available for measuring the volumes in the individual intake vent ducts. It was recognized then that it was an erroneous assumption to consider that all of the additional losses were on the discharge side, as some were on the intake side as well. In order to enable the designer to calculate the volumes of air and their distribution, further experiments were made as described in this paper.

Perhaps the most important conclusion reached as a result of the earlier experiments was that with a ventilation system as shown in Fig. 1, the influence of rotation upon the total volume of air is nearly negligible. Thus, the total volumes with the rotor vents closed, and with pressures of the order of five inches of water, were reduced about four per cent by changing the rotor speed from 0 to 3600 rev. per min. (surface velocity of 24,600 ft. per min.) With the rotor vents open, and with higher pressures, there was even a smaller reduction in volume; consequently the change between standstill and normal speed could be ignored in machines as are ordinarily built, with pressures of 10 in. of water or more.

A second important conclusion was that on the discharge side the axial distribution of volume in the vent ducts was made somewhat more uniform by the influence of rotation. The influence is less the larger the air-gap and for the air-gaps usually employed the effect of rotation upon axial distribution is quite small.[3] Undoubtedly on the intake side, there is likewise a modification in axial volume distribution due to rotation, but now, from theoretical considerations, there are probably greater differences between maximum and minimum vent-duct velocities than at standstill. But the change is doubtless quite small with the usual size of air-gap. In the large machines the coils are sunk so that there is an axial passage above them in which the flow is not disturbed appreciably by rotation. (This may be seen from the outlet vents by a comparison of Figs. 33 and 34 in the 1924 paper). Also, the tests on the turbo model were made at the reduced total end-bell pressure of about 3.3 in. of water. In the large modern machines, the end-bell pressure is considerably higher, 10 in. and more. Then all the velocities in the vents and gap are greater, and the influence of rotation upon vent duct volume distribution becomes still less. Certainly, whatever the influence of rotation is, it is sufficiently small to justify the assumption that it may be neglected.

This then meant that the study could be continued on stationary models. They could be of such reduced size that the tests could be made in a laboratory instead of in a factory, and thus not conflict with production. The conditions that obtain in a machine with axial flow in the gap are the same for all positions, circumferentially, so that a study of flow with one set of vents would be sufficient. The construction of the laboratory apparatus and the manner of conducting the experiments have been fully justified by the close agreement between the wooden turbo model and machine data and the laboratory data.

Apparatus

The vent ducts were imitated by square, brass tubes, two of which are shown in Fig. 2. From a knowledge

2. "An Experimental Study of Ventilation of Turbo Alternators" by C. J. Fechheimer, and "Multiple-Radial System of Cooling Large Turbo Generators" by Donald Bratt, A. I. E. E., 1924, pp. 476 and 467.

3. See Figs. 34 and 35 on pp. 495 and 496 of 1924 A. I. E. E. Transactions.

of the pressure drops in vent ducts obtained from earlier laboratory tests on small ducts, it was possible, by calculation, to determine how to shape the sections within the square tubes, so that the pressure drop in the individual tube would approximate the drop in a vent duct for either direction of flow. A special mandrel was made and plaster of paris was cast about this mandrel on the inside of the tubes.[4] It was found that because of lack of uniformity at the ends of the plaster of

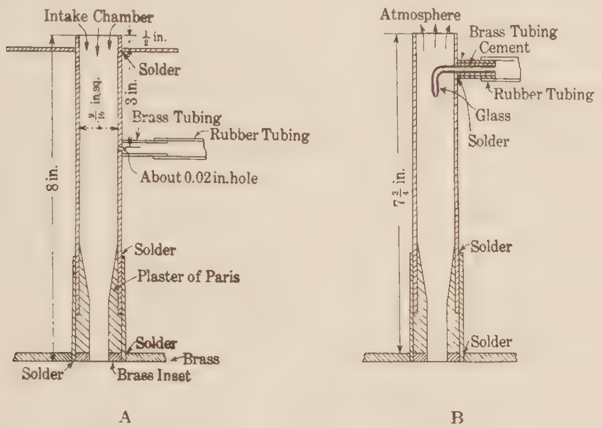

Fig. 2—Construction of Square Tubes used in the Experiments
(a) Tube representing intake vent duct
(b) Tube representing discharge vent duct

paris, there were many irregularities in the test results. Consequently, small brass insets were made as shown in Fig. 2, and the plaster of paris behind them was formed accurately to dimensions.

Fig. 2A shows one of the intake tubes and Fig. 2B one of the outlet tubes. The air enters the intake tubes from a relatively large chamber and there is a loss of head at and just beyond the entrance of air to the tube

Fig. 3—First Set-Up, Imitating the Intake Side of a Turbo Alternator

In addition, there is the velocity head itself ($v^2/2\,g$) so that the total difference in pressure from the large intake chamber to a point a little distance down the tube is approximately $1.5\,v^2/2\,g$. Hence, if a manometer is connected between the large intake chamber and a point down the tube, the readings should be of of approximately one-half of a velocity head ($1/2\;v^2/2\,g$).

4. Metals of various kinds had been tried, but had been abandoned.

such order that they could be observed with considerable accuracy. That was the principle used for measuring the volumes in the intake tubes the construction being indicated in Fig. 2A. A sample tube was tried out before all the tubes were made and the method was found to be satisfactory.

On the outlet side, the air discharges from the individual tube directly into the atmosphere. Neglecting what small friction drop there is in the tube, the static pressure a short distance from the end is nearly the same as that of the surrounding atmosphere. Consequently, the method used for measuring volumes on the intake side could not be applied to the discharge side. The construction that was adopted is shown in Fig. 2B. Inside the large square brass tube was a small impact tube which was connected by the usual rubber tubing to a manometer, the other side of the manometer being open to the atmosphere.

In using the intake tubes, the manometer was connected by means of rubber tubing between the round brass tube soldered to the square tube and the relatively large intake chamber in which latter the velocities were so low that the influence of velocity head could

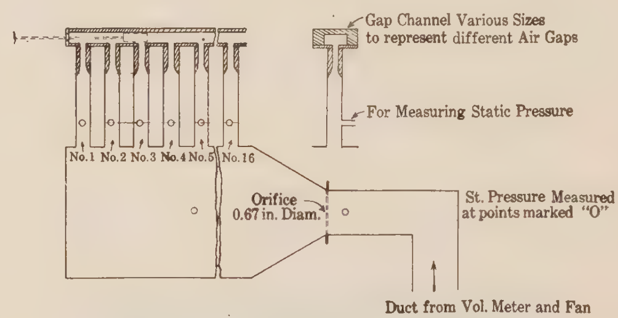

Fig. 4—Scheme of First Set-Up, Imitating the Intake Side of a Turbo Alternator

be neglected. On the discharge side, the manometer was connected to the impact tube. Each tube was carefully calibrated before any other tests were made. Due to small errors in construction which necessitated referring to the calibration data when the final data were used, the calibrations differed slightly from one another.

All tubes were soldered into brass plates about 0.25 in. thick, and were assembled in several combinations. Channels of various sections to imitate different air-gaps were made to bolt to the brass plates, rubber gaskets being used to eliminate leakage. Groups of tubes could be joined together at their ends, for which suitable flanges and bolts were provided.

There were three set-ups, two of which are shown clearly in the illustrations, Figs. 3 and 6. In Fig. 3, which shows the first set-up, intake conditions only are imitated. In Fig. 4 it is shown schematically. The second set-up imitated the discharge only and it is shown schematically in Fig. 5. In Fig. 6, for the third set-up, the ventilating system of one-half of

a generator, with one intake chamber at either side of the center line is simulated.

The apparatus was constructed so that any desired combination of intake and discharge vents could be obtained, thereby imitating the ventilating system of a machine, either in part or whole. The blower used does not appear in the photographs. It was capable of delivering the volumes required at pressures up to 10 in. of water.

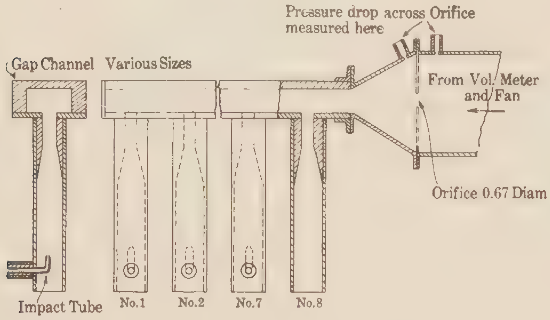

FIG. 5—SCHEME OF SECOND SET-UP, IMITATING THE DISCHARGE SIDE OF A TURBO ALTERNATOR

DIFFICULTIES IN MEASUREMENT

1. Measurement of volumes. It was at first thought that the impact tube method of measuring volumes as used for the discharge tubes would be more reliable than the entrance pressure drop method used for the intake tubes, since impact measurements are usually from which the glass impact tube had been removed. The ratio of readings taken with them did not remain position just beyond one of the square discharge tubes

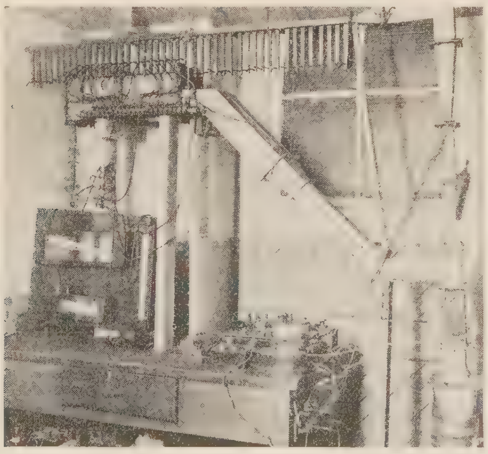

FIG. 6—THIRD SET-UP, IMITATING THE VENTILATING SYSTEM OF HALF OF A TURBO ALTERNATOR

more dependable than are those for static pressure. It was found, however, that the reverse was the case in these experiments. Thus, when taking observations of discharge volume distribution with several tubes open, some of the points did not lie on a smooth curve, which was not the case for the intake tubes. The discrepancy was of the order of three or four per cent. Four small impact tubes were supported in fixed, showing that the character of flow changed, and the other impact tubes undoubtedly were similarly affected. Apparently, the highly turbulent state in the gap channel, and immediately after entrance to the square tube was not entirely eliminated before the impact tube was reached. It is well known that, with some turbulent states, the flow may change and be periodic. These tests also proved that the character of flow in the tube is affected by the magnitude of the gap velocity. This was indicated by the fact that the volume in a duct depended somewhat upon the gap velocity, as well as upon the square root of the static pressure difference. Subsequent reference to this will be made. For the intake tubes the velocity in the large chamber was negligible, so that any flow there did not influence the drop to a point where the readings were taken.

2. Pressures in the air-gap. In order to determine where the losses of head occurred, it was necessary to know the static pressure in the air-gap as well as the average velocity there. The tests made by the "toy balloon" method described on page 496 and shown in Fig. 37 in the 1924 A. I. E. E. TRANSACTIONS, indicated that a reasonably accurate measure of the gap static pressure could be obtained by closing a vent and then observing the pressure in the vent some distance from the gap. That method was tried in these tests also. To determine the air-gap pressure at a given tube, the two adjacent tubes were closed at their far ends. The manometer readings were then the static pressure in the gap. The average of these readings for the two adjacent tubes was taken to be the desired static pressure. That this method was satisfactory was proven by subsequent tests. It was used chiefly for the discharge tubes, but it was found to check on the intake side also.

DETERMINATION OF LOSSES

A. On the Intake Side. A study of the possible sources of losses of head on the intake side indicated that they could be divided into five groups: 1, loss within the radial vent duct; 2, loss accompanying the turning of a right angle; 3, loss due to sudden increase in velocity when an incoming stream impinged upon a stream normal to it; 4, loss due to surface friction; and 5, loss at final discharge from the air-gap channel. (This last loss is $\frac{v^2\,o}{2\,g}$, and requires no further discussion). The expressions for the losses are given here; the means for separating them in the experiments are given in the complete paper.

1. Loss within the radial vent duct. The pressure drop in a vent duct had been determined in previous tests and could be represented by the equation

$$\frac{P}{\gamma} = C\,i\,\frac{V^2}{2\,g}$$

(Where p = pressure drop, γ = density, V = velocity

at the minimum section of the duct, and g = acceleration of gravity)[5]. As the velocity head at discharge from the vent duct is $\frac{V^2}{2\,g}$, the loss within the vent duct is evidently

$$(C_i - 1)\frac{V^2}{2\,g} \qquad (1)$$

2. Loss accompanying the turning of a right angle. The expression just given accounts for the pressure drop through the vent duct, provided the air-gap velocity is negligible. Usually, however, the gap velocity is appreciable which causes an additional difference between static pressure at the entrance of the vent duct and the static pressure in the air-gap. This additional pressure drop is due to the abrupt turn which the stream from the vent duct must make when it strikes the air-gap stream. This pressure drop can be represented by $K_L \frac{v^2}{2\,g}$ (where K_L is a coefficient, depending on the size of the air-gap and v is the velocity in the air-gap just past the vent duct.)

In addition to this loss in pressure there is a loss in velocity head since the velocity in the gap is almost always lower than the velocity issuing from the vent duct. This loss in velocity can be represented by $\left(\frac{V^2}{2\,g} - \frac{v^2}{2\,g}\right)$ and is caused by the sudden decrease in velocity when the air from a vent duct mixes with the air in the gap. The total pressure drop from the intake chamber to a point in the air-gap just past the vent duct is then:

$$\frac{p}{\gamma} = (C_i - 1)\frac{V^2}{2\,g} + K_L\frac{v^2}{2\,g} + \left(\frac{V^2}{2\,g} - \frac{v^2}{2\,g}\right) + \frac{v^2}{2\,g} \qquad (6)$$

The last term represents the velocity head in the gap.

3 and 4. Loss due to sudden increase in gap velocity and duct friction. As a stream from a vent duct impinges upon the stream in the air-gap, the velocity of the gap stream increases suddenly due to the increase in volume. Considerable loss is produced by the eddies accompanying this sudden increase in velocity, and this loss can be represented by $K\,\frac{v_2^2 - v_1^2}{2\,g}$.

Where v_2 and v_1 are respectively the gap velocities after and before the sudden increase in gap velocity, and K is a coefficient to be determined experimentally. It was found that K could be so chosen as to include the loss due to the duct friction in the gap as well as the loss due to sudden increase in velocity.

5. A list of symbols is given after the final equations.

Combination of loss expressions on the intake side. Let

P = Pressure in the intake chamber.
p_0 = Pressure in the gap at its discharge point. (This was atmospheric pressure in the tests described above or taken as zero for reference.)
v_0 = Gap velocity at the discharge point.

Then by Bernoulli's equation:

$$\frac{P_0}{\gamma} = \frac{p_0}{\gamma} + \frac{v_0^2}{2\,g} + \text{sum of losses from intake}$$

chamber to discharge point in gap.
or

$$\frac{P}{\gamma} = \frac{p_0}{\gamma} + \frac{v_0^2}{2\,g} + (C\,i - 1)\frac{V^2}{2\,g} + \frac{V^2 - v^2}{2\,g} + \frac{K_L\,v^2}{2\,g} + K\,\frac{v_0^2 - v^2}{2\,g} \qquad (8)$$

The accuracy of this expression for pressure drop was checked by testing a large number of intake combinations. Then, using the measured velocities and the above expression for losses, the pressure drop was calculated for each vent duct and this value was checked against the measured pressure drop. Table I shows a tabulation of these values for one test. The agreement is undoubtedly close and, therefore, the equation was taken to be sufficiently accurate.

TABLE I

I. Vent Tube Number	II. Vel. "V" in Vent	III. Total Calc. Pressure	IV. Total Meas. Press.	V. % Difference
3	9480	8.48	8.18	+3.7
5	7280	8.25	8.18	+0.9
6	6070	8.29	8.18	+1.4
7	5090	8.33	8.18	+1.8
8	4100	8.09	8.18	−1.1
9	3400	8.11	8.18	−0.9
10	2650	8.12	8.18	−0.7
11	2300	8.17	8.18	−0.1
12	2140	8.20	8.18	+0.2
13	1860	8.18	8.18	0.0
14	1620	8.17	8.18	−0.1
15	1480	8.15	8.18	−0.4
16	1420	8.15	8.18	−0.4

B. On the discharge side. On the discharge side, the air streams flow from the air-gap through parallel vent ducts out to a common discharge chamber. In these tests they discharged into the atmosphere. The losses of head were divided into four groups: 1, loss within the radial vent ducts; 2, loss accompanying the turning of a right angle; 3, loss due to sudden decrease in velocity arising when some of the fluid discharged through a vent duct; 4, loss due to surface friction. For the particular set-up there was also a small loss in the converging duct leading to the gap channel, but this loss does not appear in the machine, in the parts that are fed from the intakes. There is an entrance loss whose magnitude depends upon the entrance conditions in machines at the end-bell ends. Ap-

proximate data obtained in the turbo-model tests in 1923 permit of evaluation of the latter loss with sufficient accuracy.

1 and 2. Loss within the radial vent, and loss accompanying the turning of a right angle. As for the intake vents, the losses in the radial vents were determined at the time the tests on the turbo model

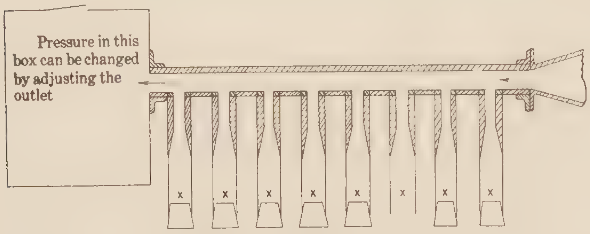

FIG. 7—SCHEMATIC DIAGRAM, SHOWING THE METHOD IN WHICH TESTS WERE MADE FOR EVALUATING LOSS CO-EFFICIENTS ON THE DISCHARGE SIDE

One vent duct was left open. All other vents were closed by rubber stoppers. The pressure in the gap can be changed by adjusting the outlet from the box at the end of the gap so that any combination of velocity and pressure can be obtained. Impact tubes located at points marked "x" give vent duct velocity head if the vent duct is open, or static pressure in the gap if the vent duct is closed by a rubber stopper

were made in 1922 and 1923. They were made with the same apparatus but the direction of flow was reversed. The co-efficient was called C_d, as defined by the equation $\frac{p}{\gamma} = C_d \frac{V^2}{2g}$. The meanings of the symbols are the same as before. It was recognized that the conditions in the machine, or in this model might be different than they were in the small set-up of 1923, because the entrance conditions were different. The loss accompanying the turning of a right angle could not readily be separated from the entrance conditions, and there was little to be gained, if that could have been done without great difficulty. Consequently those two losses were combined, and the new values of the coefficient $C\,d$ takes account of the turning of a right angle, of the entrance loss to the vent duct, and the loss in the vent itself.

In Fig. 8 will be found a plot for one test, No. 3 tube being the only one open. The value of $C\,d$ is not constant, but is dependent upon the gap velocity.

3. Loss due to sudden decrease in velocity. It was shown largely by theory and checked by experiment that when there is a sudden enlargement of cross-section, the loss of head is:

$$\frac{(v_1 - v_2)^{2*}}{2g} \qquad (10)$$

v_1 and v_2 are the velocities before and after the enlargement, as given by the volume divided by the cross-sectional area. It may, without much difficulty, be shown that the decrease in velocity in the air-gap to the abstraction of the air through the vent duct, is comparable with the case of sudden enlargement, and probably should be given by the same equation. Equation (10) was found to apply with considerable accuracy, except for the case when $v_2 = 0$. Even then the loss considered as part of the total was not great. To check equation (10) tests were made in a similar manner to those for the individual tubes, and the gap static pressure on either side of the particular tube was measured.

4. Loss due to surface friction. From the curve in Fig. 8 it will be seen that the friction loss is by no means negligible. It is given by the well-known formula to be found in any standard work on hydraulics:

$$\text{Friction drop} = f \frac{L\ R}{A} \frac{v^2}{2g} \qquad (11)$$

Wherein:

f = coefficient of friction
L = Length
R = perimeter of duct
A = Area of cross section of duct
v = velocity
g = acceleration of gravity.

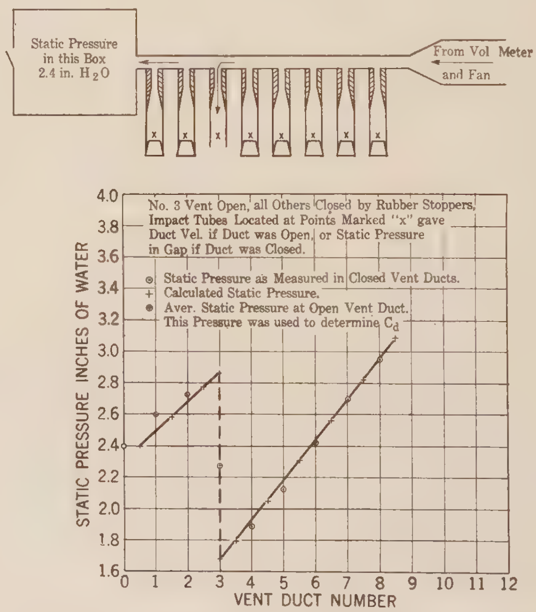

FIG. 8—EXAMPLE OF PLOTTED DATA SHOWING METHOD OF DETERMINING STATIC PRESSURE FOR EVALUATING $C\,d$

If v is in ft. per min., and the density be taken as 0.074 lb. per cu. ft., the friction drop in inches of water is:

$$f \frac{L\,R}{A} \left(\frac{v}{4030}\right)^2$$

f = about 0.0054

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*See Gibson: "Hydraulics and Its Applications." Second edition, pp. 82 and 83. The equation is quite different from what one might at first glance expect:

$$\frac{v_1^2 - v_2^2}{2g}$$

Combination of the equations on the discharge side. Consider the case where the air enters the discharge part of the air-gap from the intake side (that is, not the case where the air enters the air-gap directly from the end-bell—see Fig. 1). Then the static pressure in the gap at that division point between intake and discharge is p_0. The velocity in the gap at that point is v_0. Following the path of a stream of air from that point, to some other point in the gap, the equation by Bernoulli's theorem is:

$\frac{p_0}{\gamma} + \frac{v_0^2}{2g} = \frac{p}{\gamma} + \frac{v^2}{2g} + \sum$ losses from the division point to the point in the gap considered.

$$\frac{p_0}{\gamma} + \frac{v_0^2}{2g} = \frac{v^2}{2g} + C_d \frac{V^2}{2g}$$

$$+ \sum \frac{(v_1 - v_2)^2}{2g} + \sum f \frac{L}{A} \frac{R}{} \frac{v^2}{2g} \qquad (12)$$

Here $\sum \frac{(v_1 - v_2)^2}{2g}$ means the summation of all losses due to sudden decrease in velocity from the division line up to the particular vent duct considered; and $\sum f \frac{L\ R}{A} \frac{v^2}{2g}$ is the summation of friction drops, between the same points, account being taken of the changes in velocity. In equation (**12**) $C\,d\,\frac{V^2}{2g}$ has been written for $\frac{p}{\gamma}$.

When the air enters the gap channel directly, as was the case for the second set-up, or as is the case when the air in a machine enters the gap directly from the end-bell, and the chamber is so large that the velocity head there may be neglected, the static pressure being P, the equation is:

$$\frac{P}{\gamma} = \frac{v^2}{2g} + \frac{p}{\gamma} + \sum \frac{(v_1 - v_2)^2}{2g} + \sum f \frac{L\ R}{A} \frac{v^2}{2g} \qquad (13)$$

This latter equation was used for final checking of the discharge loss coefficients. In Table II the results of one test are summarized.

TABLE II

I Vent Tube Number	II Meas. Static Press.	III Avg. Meas.* Static Press.	IV Avg. Calc. Static Press.	V % Difference
8	7.03			
7		7.32	7.15	2.3
6	7.62			
5		7.84	7.73	1.4
4	8.06			
3		8.20	8.10	1.2
2	8.32			
1			8.25	

*Average of measured pressures on each side of open duct.

Final Equations

The expressions which have been obtained give the pressure drop when the velocities are known. However, equations to be useful to the designer must give velocities for a given pressure drop. To obtain these final expressions, the general method used by Bratt in his 1924 A. I. E. E. paper was followed. The assumption is made that there are an infinite number of vent ducts, each of infinitesimal width, instead of a finite number, each of finite width. This assumption is comparable with the one usually made in polyphase alternating-current machinery; that there is a sine wave distribution of magnetomotive forces and fluxes.

For the intake side the expression for losses could be taken just as it has been given and following the method used by Bratt an equation was obtained which had the same form as Bratt's original equation except that now the constants have been determined experimentally[6].

For the discharge side, the equation for losses as it has been given could be reduced to a differential equation but the solution was too complicated to be practical. It was, therefore, decided to make approximations which would alter the form of equation (**13**), and still be close enough for general application. The assumption was made that there were no gap losses, that $C\,d$ was constant and that its value corresponded to the highest gap velocity. This was the highest value for $C\,d$, so that compensated for having ignored the gap losses. At the division, where the gap velocity is maximum, the assumption is the same as for the actual conditions, since the value of $C\,d$ used corresponds to that point, and the gap losses there are zero. At points where the gap velocity is lower, the assumed value of $C\,d$ is too high, but since then the gap losses are neglected, the static pressure, as calculated by Bernoulli's equation, is high. As the vent duct velocity is dependent upon the quotient of the gap pressure and $C\,d$, and as both are high, the error is quite small.

Summary of Final Equations

Intake

$$v = v_0 \frac{\sinh \alpha (L_i - x)}{\sinh \alpha L_i}$$

$$V = \frac{a}{S} v_0 \frac{\cosh \alpha (L_i - x)}{\sinh \alpha L_i}$$

Discharge

$$v = v_0 \frac{\sin \beta (L\,d - y)}{\sin \beta L\,d}$$

$$V = \frac{v_0 \cos \beta (L\,d - y)}{\sqrt{Cd} \sin \beta L\,d}$$

$$P_i = \gamma \frac{v_0^2}{2g} \left[\frac{1 + K - K_L}{\sinh^2 \alpha L_i} + (1 + K) + \cot^2 \beta L d \right]$$

$$P_e = \gamma \frac{v_e^2}{2g} (1 + k + \cot^2 \beta L_e)$$

Note that to compute the velocities on the discharge side adjacent to the end-bell, the above velocity

6. The derivation of the equations is given in the complete paper.

equations may be used, but y and $L\,d$ are now measured from the end-bell end instead of from the division point, V_e must be substituted for v_0, and the value of $C\,d$ must be used that corresponds to v_e instead of to v_0.

In using the equations it is perhaps a little more convenient to take S as the area of one circle of stator vents at the minimum section, and then $L\,d$, $L\,e$ and $L\,i$ are in number of vents instead of in actual lengths.

In the above equations:

$$\alpha = \frac{S}{a}\sqrt{\frac{1 + K - K_L}{C\,i}} \qquad \beta = \frac{S}{a}\sqrt{\frac{1}{C\,d}}$$

a = Cross sectional area of the air-gap.
$C\,d$ = Discharge coefficient in the radial vent ducts.
$C\,i$ = Intake coefficient in the radial vent ducts.
k = Loss coefficient at entrance to gap, end-bell end.
K = Loss coefficient for sudden increase in velocity.
K_L = Loss coefficient for turning a right angle.
$L\,d$ = Distance from division point to balance point, discharge side.
$L\,e$ = Distance from end-bell to balance point.
$L\,i$ = Distance from division point to balance point, intake side.
$P\,e$ = Pressure in end-bell.
$P\,i$ = Pressure in the intake chamber.
S = Cross sectional area of stator vents at the minimum section per unit length axially.
v_0 = Velocity in gap at division points.
v_e = Velocity in gap at end-bell end.
V = Velocity in stator vents at minimum section.
x = Variable distance from division point, intake side.
y = Variable distance from division point, discharge side.

These equations assume that we know the balance points, *i. e.*, the points in the air-gap when the velocity is zero. These points, which we have called "balance points" are determined by the following conditions,

1. The pressure drop for all paths must be the same.

2. The vent duct velocities at the balance point must be the same when computed for the two parallel circuits which meet at that point.

On account of the transcendental form of the equations, they cannot be solved simultaneously to find the values of $L\,i$ and $L\,d$ (*i. e.*, the balance points). Consequently, a trial and error method must be used for finding them.

The velocities as calculated from these equations were checked against test results for a large number of tests. The results checked against included a large number of tests on the model described in this paper, tests on the model described in the 1924 paper and tests on actual machines. In every case the agreement was found to be satisfactory. Figs. 12, 13 and 14 show the agreement for three of these tests.

CORRESPONDENCE

HIGHWAY LIGHTING

Editor, A. I. E. E. Journal,

I am much interested in your article on Page 24, entitled, "One Genuine Method of Solving The Automobile Headlight Problem."

Ten years' ago, I made a suggestion of scientifically illuminating the highways, which suggestion was much laughed at. It seems to me that most of the light on our highways and even on our boulevards in the city, is wasted by being up in the air. It seems to me that the primary purpose of illuminating a highway, is to illuminate the road itself, and that it does not matter whether or not anything above the road is illuminated.

My suggestion is that along the sides of the highways weather-proof lights, down low like footlights, be installed to thoroughly flood the highway without any light at all coming direct in the eyes of the motorist or even the pedestrian. That is, these lights would be installed low and so shaded that a highway would look like one broad ribbon of light.

If this were done, no head lights at all would be needed on any automobiles and all that would be necessary would be small pilot lights and a tail light, sufficient only to indicate the presence of the car. What do you think of this?

TALIAFERRO MILTON

NEW POWER PROGRAM IN GREAT BRITAIN

The new electrical power program of Great Britain, outlined by the Prime Minister, will be presented to Parliament during the coming session. This electricity bill, if passed, will be of great interest to the country as a whole, and will vitally affect its industries.

The main objects of the bill are the standardization of the frequency, at an estimated cost of £10,000,000; the laying of interconnecting cables between industrial areas; the reduction of the number of generating stations from 584 (at present) to 60; and the lowering of rates for electric current.

NATIONAL POWER BOARD TO DETERMINE POLICY

The plan outlined by the Prime Minister includes the creation of a national power board which will deal with matters of policy. The present electrical commissioners are to continue as technical advisors with particular reference to standardization and unification work now in progress, which, owing to the increased power granted, will be expedited. One result has been a rise in electrical shares on the exchange.

The sites for the new generating stations will, as far as possible, be on rivers and canals. It is estimated that it will take 15 years to develop this project and that ultimately the annual consumption of electricity in the United Kingdom will be raised to at least 500 kilowatt-hours per capita.

The Magnetic Hysteresis Curve

BY HANS LIPPELT[1]
Member, A. I. E. E.

Synopsis.—*An analysis of the phenomena of hysteresis is presented in the paper which introduces the conception of a reactive component and a dissipative component of the counteracting force, which appears when magnetizeable material is subjected to a magnetizing force. Using this conception, equations and curves are developed for the hysteresis curve, for the various components and for the hysteresis loss. The loss is shown to depend directly on the dissipative component.*

I. Nature of the Problem

1. The purpose of this paper is an analytical study of the fundamental character of magnetic hysteresis with a view to formulating, if possible, reliable mathematical terms in convenient form.

Foremost among the historical works along this line is that by Hopkinson (giving a theory of the magnetic circuit), which was well augmented by Fröhlich as published in the *Elektrotechnische Zeitschrift* of 1881, pages 90 and 139; and a treatise by Professor Kennelly printed in the TRANSACTIONS of the A. I. E. E. 1891, page 485.

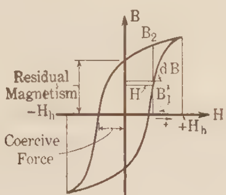

FIG. 1

The most familiar representation of magnetic hysteresis is the well-known loop, as shown in Fig. 1, in which the salient features are duly emphasized.

2. *Nature of Forces Involved in the Process of Magnetization.* As will be explained, the process of magnetization of the so-called magnetic metals and alloys seems to involve three forces.

(a). Magnetizing force H, which tends to produce magnetic induction in the material in the direction of H.

(*b*). Reactive force R, which tends to demagnetize the material, that is, to reduce the induction to zero. It seems to be a force of the nature of internal elastic stress, similar to a reactive tension.

(*c*). Dissipative force D, which opposes *changes* of magnetic induction. It seems to be a force of the nature of (molecular) friction and tends to maintain the material in the state of magnetization in which it happens to be at the moment.

The first force, H, is of external origin, being produced usually by an electric current.

When the magnetic circuit contains an iron core the total flux per sq. cm. of cross-section is

$$B = H + 4\,\pi\,I = H + \beta \qquad (1)$$

where $\beta = 4\,\pi\,I = B - H$ is called the intrinsic induction in the iron.

To better illustrate the relations, let us assume that a magnetic hysteresis curve $B_1\,B_2$ has been determined by experiment, Fig. 2. Its course is indicated by dotted lines, $B_1\,B_2$. True to definition corresponding curves β_1 and β_2 have been produced by subtracting from the ordinates of $B_1\,B_2$ the corresponding abscissas, H.

3. *Manifestation and Character of Forces R and D.* That the external force H cannot be the only force entering into the process of magnetization may readily be understood from the axiom of physics, according to which any action entails a reaction. H represents the action in this case and two forces, R and D, the reaction. That becomes particularly evident from observations which are common to the well-known experiment of magnetizing iron by an electric current, and which it becomes necessary to again review.

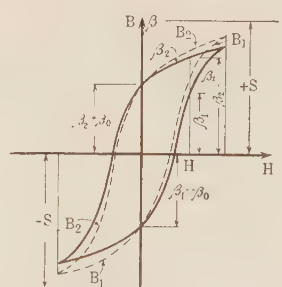

FIG. 2

(*a*). When an electric current flows through the spool, a magnetic field H is created within its cross-sectional area. This field H acts upon the iron core and causes it to become traversed by a strong magnetic flux β of the same direction as H. The iron will hold that flux as long as the magnetic field H exists. This indicates a tendency of H to produce (impress) induction in the iron in the direction in which it operates.

(*b*). Now if we interrupt the current, the magnetic field H will disappear and with it most of the magnetism β of the iron. This abatement of magnetism can be explained by the assumption of an internal

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force R, which tends to drive the magnetic flux β out of the iron, as an elastic reaction (tension) would do. Therefore, R is of opposite sign to H.

(*c*). If we put the current on again, there will reappear both the field H and the magnetism β. With the presence of R conceded under *b*, we will now have to broaden our conclusion (*a*) to the extent that the field H causes magnetism to be impressed upon the iron even against the opposing force R. Since the degree of magnetization is the same for the same recurring field H, it is likely that R depends on the degree of magnetization, the latter reaching the steady state, when its sequel, the tension R, has likewise reached its original value. On the other hand, if R were not present, magnetization should be expected to rise to any abnormal value.

(*d*). If we increase (or decrease) the field H over (or under) the value obtained under *c*, it will be followed by a strengthening (or weakening) of β. β coming in each case to a steady state when its associate reaction R has adjusted itself to the new value of H. Therefore, R is surely a function of the quantity β

$$R = F(\beta)$$

If no other forces were contingent upon the process, there should be $R = -H$, because in physics the reaction is always equal and opposite to the action. This also fixes the dimension of R to be the same as that of H, namely $C^{-1/2} G^{1/2} S^{-1}$.

It will be shown however, that these two forces R and H do not suffice to explain all the magnetic states, nor any one of them completely. A third force will exhibit itself when existing conditions are scrutinized more thoroughly.

(*e*). If the flow of current be interrupted altogether, it will be found that also, most of the magnetism has been lost but not all of it. Residual magnetism, either $\beta_2 = +\beta_0$ or $\beta_1 = -\beta_0$ has been retained in the iron, particularly so when the material under test is hardened steel (Figs. 1 and 2).

Consistent with the above reasoning the presence of that residual magnetism β_0 ought to entail a residual reaction R_0. Since the field $H = 0$ (when no current flows), there would now be no force counteracting the reaction R_0 and all the magnetism should disappear from the iron. As it does not disappear, we are compelled to admit the existence of another, a second internal force. We recognize at once one of the characteristics of this new force; namely, it tends to *resist changes* in the magnetic state existing in the iron at the time, inasmuch as the residual magnetism continues to exist in a permanent magnet. The nature of that force, therefore, seems to be that of a friction. It will be designated by the letter D.

When the field $H = 0$, this friction has the special value D_0 and balances up against the internal tension R_0. Thus

$$D_0 + R_0 = 0$$

and the coincident state of magnetization is expressed by one of the two equations

$$\text{either } \beta_2 = +\beta_0 \text{ or } \beta_1 = -\beta_0$$

as per Fig. 2.

The fact that for any other value of H we observe likewise two values of β (Fig. 2) is proof enough of the magnetic friction D obtaining for all states of magnetization. D manifests itself particularly by the difference between β_1 and β_2 where the changes of β are large as referred to unit changes of H (*e. g.*, where the β curves are steep), and abates where they are small. Hence

$$D = F_1(\Delta\beta)$$

To amplify this reasoning, let us remember that for rapid changes of β (*e. g.*, $\Delta\beta$ = large), the reaction R also changes rapidly. Since H was assumed to change in unit steps only, D must necessarily make up for the rapid changes of R, which in turn conform to rapid changes of β, that is to $\Delta\beta$. This argument is also consistent with the force D being a "resisting" force and for this very reason D is negative, when $\Delta\beta$ is positive and vice versa.

It is obvious that the dimension of D is likewise $C^{-1/2} G^{1/2} S^{-1}$ because only forces of like character can enter into a play of action and reaction.

This force D will after further study reveal itself as the actual cause of hysteresis.

Having conceded three forces H, R and D to govern the process of magnetization, we were able to explain all and any conditions observed to exist in a magnetized material. To do that *all* of these *three forces* were *necessary*, but it is also evident that they are sufficient. The *magnetization* (β), however, when in the steady state depends on the equilibrium of those three forces. That is mathematically expressed in general by

$$H + D + R = 0 \qquad (2)$$

and when applied to the ascending branch β_1 by

$$H_1 + D_1 + R_1 = 0 \qquad (3)$$

and to the descending branch β_2 by

$$H_2 + D_2 + R_2 = 0 \qquad (4)$$

Our problem was outlined in the first paragraph of Section I. It amounts, among others, to finding a formula $\beta = f(H)$, expressing in explicit terms the relation between the field H and the magnetization β. After what was said, this problem resolves itself now into two separate problems, *i. e.*, to determine, primarily the equations for R and D as functions of H; and in conjunction therewith functions expressing R and D in terms of β.

II. Equation of Reactive Force $R = F(\beta)$

4. *Relation of R to β near Saturation.* It is known that the magnetization β of a magnetizable material can rise only to its saturation value S as a limiting value. When magnetization is approaching saturation, it will do so gradually and $\Delta\beta$ is small for large changes of H. Small variation of β, however, entails a negligible

force D and such a state of affairs in connection with equation (**2**) will be used as a guide for finding a mathematical relation between R and β.

5. *Law of Magnetization near Saturation.* As is well known, the curve of β plotted against the field intensity H as abscissa approaches, for large values of H, an asymptote, which runs parallel to the H-axis at a distance S = maximum value of β, Fig. 3.

That figure confirms the statement made in the foregoing paragraph (4) that β increases only little for large

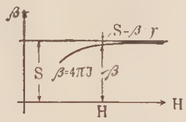


FIG. 3

increments of H. In other words the difference

$$S - \beta = \gamma$$

decreases rather slowly, because $\Delta\beta$ is small and so is the magnetic friction D.

Since the large external action H *must* meet a large internal reaction, it becomes necessary to ascribe a *large* value to the internal magnetic tension R. This quantitative relation becomes very plausible, when comparing the magnetism impressed upon the iron with an elastic medium being heavily compressed in a suitable container. (See Appendix I).

A law that is true in physics for compressed elastic mediums may apply also in our case of magnetism being impressed under similar symptoms upon suitable materials. That law applied will fix the internal reactive tension R as being inversely proportional to the capacity of the material for further magnetization. If $+ S$ is the saturation value and β the amount of magnetism impressed by a positive field $+ H$, the capacity for further magnetization is

$$\gamma = S - \beta$$

(See Fig. 3.) Under our assumption, the reactive component R would be expressed by

$$R_+ = - \frac{K}{S - \beta} = - \frac{K}{\gamma} \qquad (\mathbf{5})$$

where K is a factor of proportionality depending on the units selected for β and R. R_+ has been written to refer it to positive values of H and β.

In formula (**5**) the constant $- K$ is that reactive tension which exists when $\gamma = 1$.

We had to place the minus sign before the right hand side of formula (**5**) because R_+ is of a direction opposite to H (and also β), which we had assumed positive.

6. *Applying formula* $R_+ = - \dfrac{K}{\gamma}$ *to the whole range of magnetization.* This relation (**5**) applies, strictly speaking only to the range near positive saturation. So long as the contrary is not proven, it is well worth while to try out its alleged validity for the whole range of magnetization and study the effect. Such an initial study of R, without paying attention to D, appears all the more justified, because R is a force depending on the degree of magnetization, while D depends primarily on the quality of the material.

In order to better understand this relation between β and R_+, a curve has been drawn up (Fig. 4) corresponding to formula 5. It proves to be an equilateral hyperbola, whose one axis coincides with the axis of abscissas β, while the other is parallel to the axis of ordinates at a distance equal to $+ S$, *e g.*, the saturation value of β.

For values of β approaching $+ S$, R_+ grows infinitely large and is of negative sign. For smaller values of β the numerical value of R_+ decreases first rapidly then slowly until it attains

$$\text{when } \beta = 0 \text{ a value } R_+ = - \frac{K}{S}$$

According to our curve, Fig. 4, R_+ continues to have negative values and does not become zero until

$$\beta = - \infty$$

Returning now for a moment to Fig. 2, we notice that for heavy negative values of field intensity H, the value of β approaches a negative maximum $- S$. Formula 5 and curve Fig. 4, both yield for this value of $\beta = - S$

$$R_+ = - \frac{K}{+ S - (- S)} = - \frac{K}{2\,S}$$

while we should expect an infinitely large value for R in conformity with our previous reasoning.

7. *Adapting the law of reactive tension R to negative magnetization.* This discrepancy of the quantitative relation between R and β, which became evident with negative magnetization, may easily be taken care of by

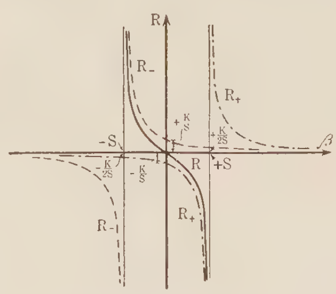


FIG. 4

repeating, for that condition, the application of the law of stressed elastic mediums.

Similar to the process carried out in chapter (**5**) we write now for strong negative magnetization.

$$R_- = - \frac{K}{(- S) - \beta} = + \frac{K}{S + \beta} \qquad (\mathbf{6})$$

Formula (**6**) as well as formula (**5**) represents an equilateral hyperbola (Fig. 4), and in this curve the

same discrepancy as that encountered above is here confronted in reversed form for $\beta = +S$.

8. *Modification of the Law of Inverse Proportionality.* The validity of each individual formula (**5**) and (**6**) to the limited zone of magnetization near positive or negative saturation respectively renders both of them unsuitable for general use. The situation is aggravated by the duplicity of value for R when $\beta = 0$, as given above $\left(R_+ = -\frac{K}{S} \text{ and } R_- = +\frac{K}{S} \right)$.

Even if it were conceded that formula (**5**) holds for positive magnetization and formula (**6**) for negative magnetization, the discontinuity and an abrupt change from $-\frac{K}{S}$ to $+\frac{K}{S}$ at zero magnetization is not compatible with the behavior of elastic mediums, which had been referred to for comparison (see Appendix I).

However, continuity is a necessary prerequisite and that can readily be obtained by admitting the simultaneous validity of both formulas (**5**) and (**6**). Such a step finds its mathematical expression in the following form.

$$R = R_+ + R_- = -\frac{K}{S - \beta} + \frac{K}{S + \beta}$$

or

$$R = -\frac{2\,K\,\beta}{S^2 - \beta^2} \qquad (7)$$

Formula (**7**) is the sum of the two terms 5 and 6 and so is curve R in Fig. 4 the composite curve of the individual curves R_- and R_+.

The new curve has actually three branches, but the two external ones, which belong to abscissas whose numerical values are larger than S, are at present of no utility. Our present consideration shall be limited to the range between $+S$ and $-S$.

Of the unknown quantities contained in equations (**3**) and (**4**) two may now be considered known, namely

$$R_1 = -\frac{2\,K\,\beta_1}{S^2 - \beta_1^2} \qquad (9)$$

$$R_2 = -\frac{2\,K\,\beta_2}{S^2 - \beta_2^2} \qquad (10)$$

9. *Determination of Constants S and K.* One of these constants, S, depends surely on the magnetic quality of the material under consideration. Experiments have shown that.

Whether and to what extent K depends on the material is still to be proven by tests. Primarily K is a special value of magnetic tension.

From a few coordinated values of β near saturation, the saturation value S itself can be found by extrapolation with sufficient accuracy.

The same test readings of H and β will lend themselves to the determination of the constant K, when recourse is had to formula (**7**) and $-H$ is substituted for R.

Another method for determining K is explained below in connection with the study of force D.

10. *Conclusions in Regard to reactive Tension R.* We have seen that: (*a*). The reactive component R of the internal counteracting force is a force of the nature of elastic recoil. (*b*). This force R is caused by and is a mathematical function of the magnetic induction β. (*c*). The relation of R to β may be expressed hypothetically by the equation $R = -\frac{2\,K\,\beta}{S^2 - \beta^2}$ (*d*). Although the reliability of this equation has been demonstrated by experimental data pertaining to but one material, its plausibility can be enhanced by the agreement of its corollaries with known facts and theories. (See Appendix I).

(*e.*) For values of β near saturation, the equation reduces itself to the form $R = -\frac{K}{\gamma}$ (Appendix I).

Under these same limitations Fröhlich's law is reduced to the form $H = \frac{K}{\gamma}$. It follows that $R + H = 0$ and that magnetic friction D and hysteresis are negligible near saturation. This conclusion is in harmony with known facts.

(*f*). For small values of β the equation reduces itself to the form $R = -\frac{2\,K}{S^2} \times \beta$ which makes it very analogous to Hooke's Law for elastic bodies. (Appendix I).

III. Equation of Dissipative Force D

11. *Review and Aspect.* The ultimate object before the author was the establishment of an equation which relates the magnetization β to the field H. Our basic equation (**2**) harbors the solution of the problem in so far as it ties into a law three magnetic forces which in turn are related to β and H.

The force R proved to be a force having the magnetization β as its cause and being quantitatively related thereto as per equation (**7**).

The dissipative force D, however, depends on the magnetic quality of the material magnetized. To study the character of this force D and its magnitude necessitates, therefore, a recourse to actual test of suitable materials.

Should we succeed in developing for this force D mathematical terms containing D as a function of H or β, the analytical representation of the magnetic hysteresis curve would then become possible.

(*12*). *Exploitation of Experimental Data.* For the purpose of investigating to what laws the internal

friction D (*i. e.*, D_1 and D_2) is subject, we employ a hysteresis curve that shows clearly the properties in question. By experiment the writer has determined such a curve for a material known as Hardened Tungsten Steel. The β-curve for this material is shown in Fig. 5.

The method employed was the step-by-step method applied to Hopkinson's Divided Bar, using also a ballistic galvanometer.

The curve is composed of two branches, β_1 and β_2. Only the β_2-branch has been plotted from observed data, because the observed results for the β_1-branch may contain errors of observation. Ascertainment of degree of accuracy is not possible now. The β_1-branch shown is a copy of β_2-branch by virtue of symmetry.

13. *Numerical Values for K and S.* In order now to apply equations (**9**) and (**10**) to our curve, the values of S and K ought to be known.

From the curvature of β curve near its highest ordinates (Fig. 5), $S = 16000$ is estimated by graphical extrapolation.

To determine K, curves were plotted first taking K as an arbitrary constant which was later corrected as will be explained. For plotting these curves equations (**9**) and (**10**), $R = -\dfrac{2\,K\,\beta}{S^2 - \beta^2}$, were made use of. By their aid $+ R$ could be plotted as a function of β (similar to Fig. 4). However, it was found more useful to plot $- R$ as a function of H. The hysteresis curve, Fig. 5, gives values of H corresponding to different values of β and by use of these values, taken from the hysteresis curve, it was possible to plot $- R$ as a function of H.

The curves for $- R_1$ and $- R_2$ so plotted are shown in Fig. 5. This Fig. 5, however, shows the final corrected curves which were not obtained until the correct value of K had been determined.

As already mentioned, K was first given an arbitrary value and the curves for $- R_1$ and $- R_2$ were plotted against H. An inspection of these original curves showed that for large values of H they approached the straight line $H_{ordinate} = H_{abscissa}$. Knowing this it was possible to plot the curves to their true scale as shown in Fig. 5. Also the true value of K could be determined and it was found to be $K = 0.5682 \times 10^6$ for the sample tested.

14. *Curves for D_1 and D_2 as depending on Field H. Permanent Magnets.* As $- R = (H + D)$ it is possible to get values of D from the $- R$ curves in Fig. 5. This was done and curves for D_1 and D_2 as functions of H were accordingly plotted in Fig. 5. $(- R - H = D)$.

Observe that the ordinates of D_1 are negative, while those of D_2 are positive.

Of special interest is the maximum value, which—referring to curve D_1—occurs for

$$H_1 = \text{approximately } + 36\, C^{-\frac{1}{2}}\, G^{+\frac{1}{2}}\, S^{-1}$$
$$D_1 = \text{approximately } - 70\, C^{-\frac{1}{2}}\, G^{+\frac{1}{2}}\, S^{-1}$$

Furthermore for

$$H_1 = 0 \text{ we have } \begin{cases} D_1 = -\ 61.5\, C^{-\frac{1}{2}}\, G^{+\frac{1}{2}}\, S^{-1} \\ \beta_1 = -\ 9230\, C^{-\frac{1}{2}}\, G^{+\frac{1}{2}}\, S^{-1} \\ +\ R_1 = +\ 61.5\, C^{-\frac{1}{2}}\, G^{+\frac{1}{2}}\, S^{-1} \end{cases}$$

When no external field H exists the two internal forces D_1 and R_1 (also D_2 and R_2) are numerically equal, but of opposite sign and therefore balance one another.

If we now go along curve β_1 (Fig. 5) from value $-$ 9230 units, where $H = 0$ to $-$ 8000, which represents a decrease in the magnetic flux, we get for this lower state of magnetization

$$R_1 = +\ 47.4\ C^{-\frac{1}{2}}\, G^{\frac{1}{2}}\, S^{-1}$$
$$D_1 = -\ \ 68.4\ C^{-\frac{1}{2}}\, G^{\frac{1}{2}}\, S^{-1}$$
$$H_1 = +\ 21.\ \ C^{-\frac{1}{2}}\, G^{\frac{1}{2}}\, S^{-1}$$

This means for this decrease in flux the internal friction D_1 has increased and is stronger than the internal tension R_1, which has decreased. Therefore,

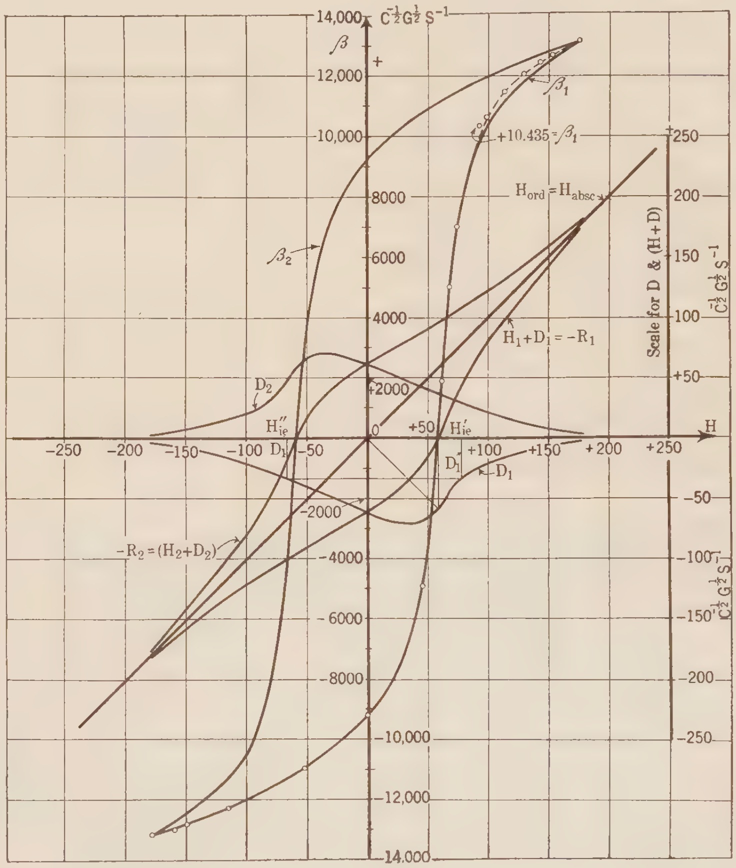


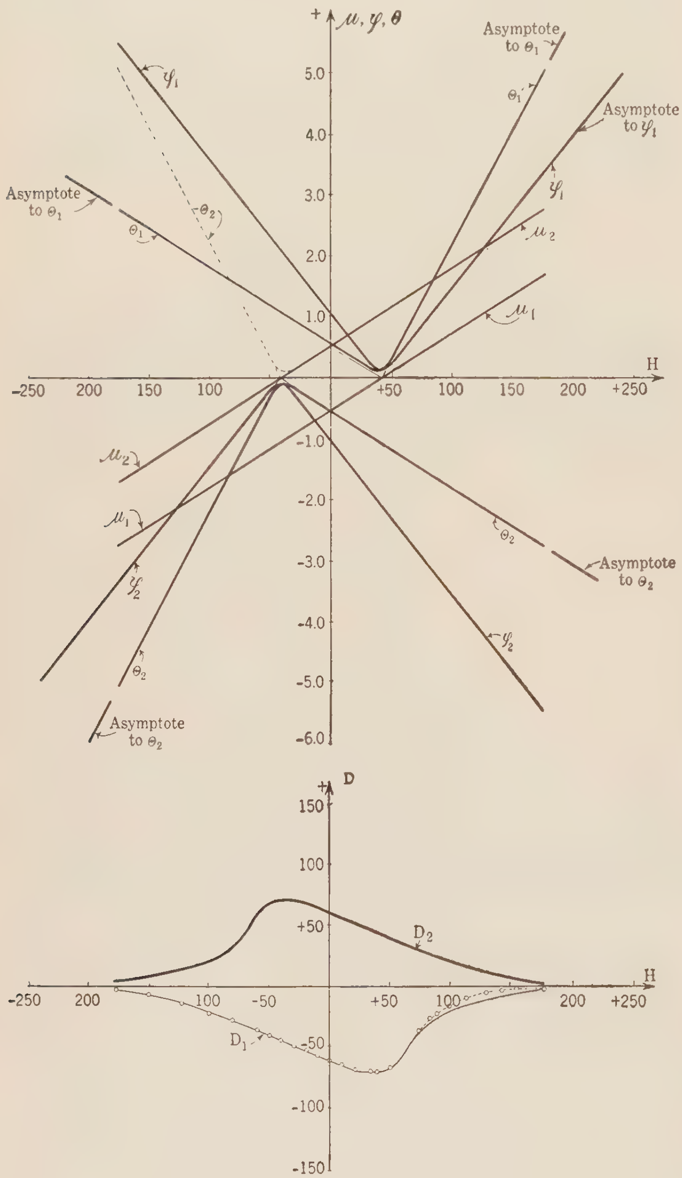
FIG. 5

without the addition of $H_1 = +\ 21$ to force R_1, the magnetism within the iron could not diminish. This fact explains the phenomenon of permanent magnets. We may put it in this way.

"In permanent magnets magnetic friction and reactive tension are equal. For diminishing flux the fric-

tion increases, while the tension decreases. Therefore, the flux *cannot* decrease as a result of the reactive tension."

Also for other small and increasing values of H_1 the magnetic friction is both increasing and greater than the reactive magnetic tension, being smaller and diminishing. Such conditions will obtain until D_1



FIGS. 6-7

reaches its maximum value. After that, both D_1 and R_1 are decreasing, and, as a sequel, the magnetization β_1 of the steel does rapidly decline.

For $\beta = 0$, we have $\left\{ \begin{array}{l} - D_1 = + H_1 = \text{approx.} + 59 = \\ \qquad \text{the coercive force} \\ R_1 = 0. \end{array} \right.$

For this condition magnetic friction and field intensity counteract and cancel one another, while the magnetic tension is zero.

For further rising field strength the magnetization β_1 increases rapidly at reversed (positive) values, owing to a rapid receding of D_1. The increase in flux, however, will soon cause R_1 to rise and the increments in magnetization, as referred to constant increments in field intensity, become smaller and smaller the more we approach the highest value of β_1. At the same time the magnetic friction D_1 converges towards the limit zero, while the reactive magnetic tension R_1 is striving towards an infinitely large value.

15. *Mathematical Relation of D and H.* After having analyzed in a general way the curves plotted from observed data, the problem remains to find mathematical terms, expressing the intrinsic and mutual relations of all the forces involved and of the flux.

As regards the D curves discussed above it was possible to get a mathematical relation between D and H. The method of deriving this relation is given in Appendix II. It was found that the graphical curves D_1 and D_2 are closely satisfied by the following equations.

$$D_1 = - \frac{A}{\cosh \theta_1} \tag{11}$$

with

$$\left. \begin{aligned} \theta_1 &= u_1 + \varphi_1 \\ u_1 &= + c\,(H_1 - f) \\ \varphi_1 &= + q \sqrt{p + u_1^2} \end{aligned} \right\} \tag{12}$$

and

$$D_2 = + \frac{A}{\cosh \theta_2} \tag{13}$$

with

$$\left. \begin{aligned} \theta_2 &= u_2 + \varphi_2 \\ u_2 &= + c\,(H_2 + f) \\ \varphi_2 &= - q \sqrt{p + u_2^2} \end{aligned} \right\} \tag{14}$$

For the sample tested the constants are as follows $A = 70.061\ C^{-1/2}\ G^{1/2}\ S^{-1}$; $f = 42$; $c = 0.012545$; $p = 0.003255$; $q = 2$

In connection with these equations the respective curves have been computed and drawn up in Figs. 6 and 7. Fig. 6 shows the graphs for u_1, φ_1, θ_1 and u_2, φ_2, θ_2, while in Fig. 7 a copy is given of the D_1 and D_2 curves as plotted from *observed* results.

In curve D_1 a few small circles indicate such points of D_1 curve as have been computed by formula (**11**).

IV. MAGNETIC FLUX

16. *Relation of β to R.* By solving equations (**9**) and (**10**) for β_1 and β_2 respectively, we get in general

$$\beta = + \frac{K}{R} - \frac{1}{R} \sqrt{K^2 + R^2 \times S^2} \tag{15}$$

Values for β_1 and β_2 have likewise been computed. Between observed and computed values of β_1 and β_2 an agreement of even better degree than for D_1 (Fig. 7) is apparent in Fig. 5. And such better agreement is due to the fact that quantity $R = -(H + D)$ enters into formula (**15**). If D were not quite correct, the error would not manifest itself any more, than D partakes in the sum $R = -(H + D)$.

Deviation between observed and computed values is indicated for the β_1 branch only by a dotted line (Fig. 5).

However, for $H_1 = +93.4$ the *observed* value $\beta_1 = +10435$ has been plotted and it falls very close to the computed (dotted) line. The above formulas may, therefore, be considered as being correct to satisfy any reasonable demands.

The term on the right hand side of formula (**15**) permits of a nice transformation. Move the product $R^2 S^2$ outside the square root and write:

$$\beta = S\left[\frac{K}{S R} - \sqrt{\left(\frac{K}{S \times R}\right)^2 + 1}\right]$$

By applying now the following substitution

$$\frac{K}{S R} = \sinh\psi \text{ or } \psi = \sinh^{-1}\frac{K}{S R} \tag{16}$$

our formula will turn into

$$\beta = \pm S\,[\sinh\psi - \cosh\psi] = \mp S \times e^{-\psi} = \mp S\frac{1}{e^{+\psi}} \tag{17}$$

For the exponential form we have

e = 2.7188 the base of hyperbolic logarithms

ψ = a positive hyperbolic angle

$-$ sign applies when R is positive (β = negative)

$+$ sign applies when R is negative (β = positive)

These relations are represented graphically by full line curve in Fig. 4.

By substituting in formula (**15**) for R the term $-(H + D)$, with D as per equations (**11**) and (**13**), β may be expressed in terms of H:

$$\beta = +\frac{K}{-\left(H + \dfrac{\mp A}{\cosh\theta}\right)} - \frac{1}{-\left(H + \dfrac{\mp A}{\cosh\theta}\right)} \times \sqrt{K^2 + \left(H + \frac{\mp A}{\cosh\theta}\right)^2 \times S^2} \tag{18}$$

and this is the equation of the Hysteresis Curve.

V. Energy Loss and Other Relations

17. *Loss of Energy.* This problem of the hysteresis curve would not be completely answered without stating the so-called hysteresis loss.

As known, this loss in ergs is computed by (Fig. 1)

$$L = \frac{V}{4\pi}\int_{-Hh}^{+Hh}{}^{-Hh} H\,d\,B = 2\frac{V}{4\pi}\int_0^{-Bh}(H_1 - H_2)\,d\,B\ (C^2 G S^{-2}) \tag{19}$$

whereby V is the volume of the magnetized material in cubic-centimeters and $\int_{-H_h}^{+H}{}^{-H_h}$ indicates that we have to integrate between the limits from $-H_h$ to $+H_h$ and back to $-H_h$. H_h is the highest field intensity attained.

Observing now equation (**1**) our integral dissolves into

$$L = \frac{V}{4\pi}\int_{-Hh}^{+Hh}{}^{-Hh} H\,d\,H + \frac{V}{4\pi}\int_{-Hh}^{Hh}{}^{-Hh} H\,d\,\beta$$

The value of the first of those two integrals is nil, leaving for the loss

$$L = \frac{V}{4\pi}\int_{-Hh}^{+Hh}{}^{-Hh} H\,d\,\beta = \frac{V}{4\pi} \times I \tag{20}$$

$I = \int_{-Hh}^{+Hh}{}^{-Hh} H\,d\,\beta$ represents the area within the loop $\beta_1\,\beta_2$ of Fig. 2.

Designating the highest value that β attains by β_h and by further transformation we get

$$I = -2\left\{\int_{\beta_1=0}^{\beta_1=\beta h}\beta_1\,d\,H_1 - \int_{\beta_2=0}^{\beta_2=\beta h}\beta_2\,d\,H_2\right\} \tag{21}$$

The following equations (**15**), (**9**), (**10**), (**3**), (**4**), made use of in the order named, will permit to express these integrals in terms of H, and eventually yield the loss thus:

$$L = -\frac{V}{2\pi}\left\{+\int_{+H_o}^{+H}\left(-\frac{K\cosh\theta_1}{H_1\cosh\theta_1 - A} + \frac{1}{H_1\cosh\theta_1 - A} \times \sqrt{K^2\cosh^2\theta_1 + (H_1\cosh\theta_1 - A)^2 S^2}\right)d\,H_1 - \int_{-H_o}^{+Hh}\left(-\frac{K\cosh\theta_2}{H_2\cosh\theta_2 + A} + \frac{1}{H_2\cosh\theta_2 + A} \times \sqrt{K^2\cosh^2\theta_2 + (H_2\cosh\theta_2 + A)^2 \times S^2}\right)d\,H_2\right\} \tag{22}$$

with θ_1 and θ_2 as per equations (**12**) and (**14**) and

$H = +H_0$ when $\beta_1 = 0$ $H = -H_0$ when $\beta_2 = 0$.

highest value attained by H is H_h.

Similarly

$$I = -2\int_0^{\beta h}\beta\,(-d\,D_1 + d\,D_2) = -2\int_0^{\beta h}\beta\,d\,(-D_1 + D_2) \tag{24}$$

and the loss

$$L = -\frac{V}{4\pi}2\int_0^{\beta h}\beta\,d(-D_1 + D_2) = -\frac{V}{2\pi}\int_0^{\beta h}\beta d(-D_1 + D_2) \tag{25}$$

also

$$L = +2\frac{V}{4\pi}\int_0^{\beta h}(-D_1 + D_2)\,d\,\beta \tag{28}$$

The solution of this latter integral requires D_1 and D_2 or $(-D_1 + D_2)$ as a function of β. That will be accomplished in the next chapter.

But it may be remarked here that the differential

of energy loss, according to formula (**28**), reveals itself as the product of the magnetic friction times the change in the flux, to wit:—"friction times magnetic current." Formula (**28**) in this form $\frac{dL}{dt} = \frac{V}{2\pi}(-D_1 + D_2)\frac{\partial \beta}{\partial t}$ expresses the "Hysteresis Power

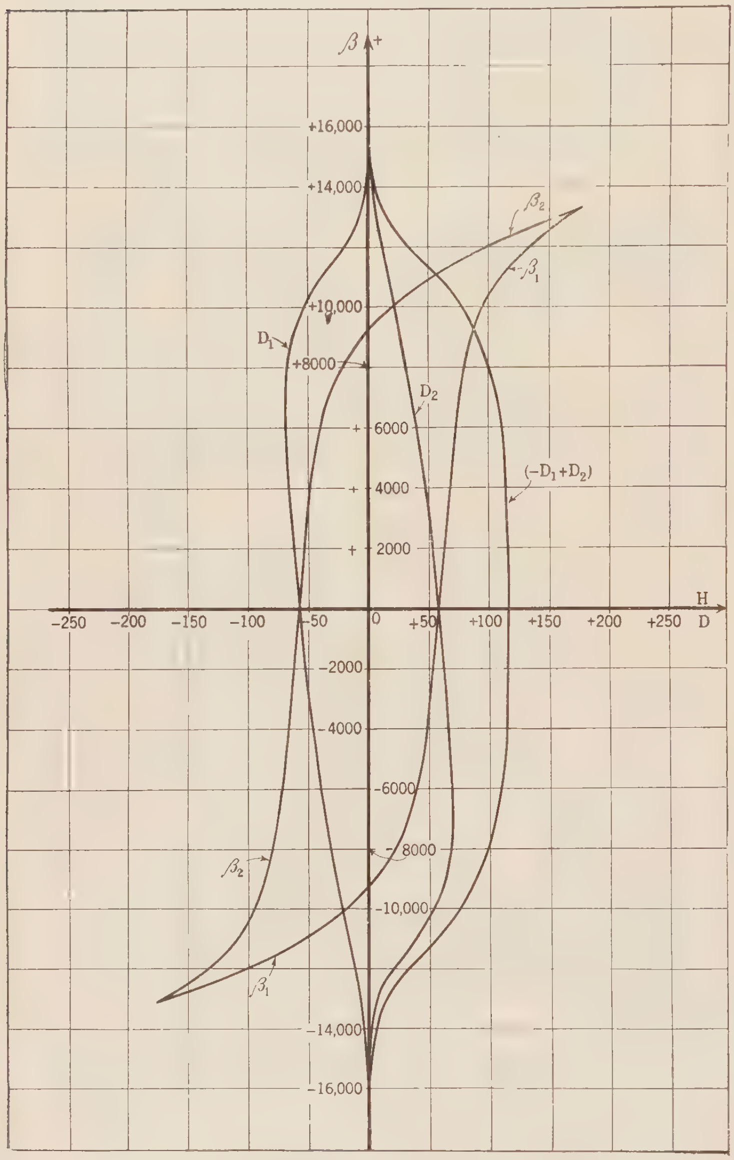


Fig. 8—Magnetic Hysteresis Curve

Loss" as being proportional to the product "Force of Friction times Magnetic Current."

12. *Magnetic Friction D as a function of induced flux β.* Fig. 8 shows the curves of magnetic friction D_1 and D_2 over the induced flux β as abscissas.

These curves D_1 and D_2 were derived by transposing the ordinates D_1 and D_2 from their H abscissas to such β abscissas as are coordinated to the H abscissas.

No matter between what limits the magnetic cycle occurs, for $H = \pm \infty$ the values of D_1 and D_2 are zero and those of β_1 and β_2 are $\pm S$.

Consequently our two curves D_1 and D_2 must have zero points for the abscissas $+S$ and $-S$. This enables us to consider D_1 and D_2 as two half waves of two combined sine and cosine series with higher harmonics.

Referring now to curve D_1 particularly, its equation has been determined on that basis, using a method developed and described by Prof. Runge,[2] namely

$$D_1 = 10^{-3} \times S \sum \left(b_n \sin n \frac{\pi}{2} \frac{\beta_1}{S} + a_n \cos n \frac{\pi}{2} \frac{\beta_1}{S}\right) \tag{29}$$

and

$$D_2 = 10^{-3}\, S \sum \left(b_n \sin n \frac{\pi}{2} \frac{\beta_2}{S} - a_n \cos n \frac{\pi}{2} \frac{\beta_2}{S}\right) \tag{30}$$

with

$n =$	1	3	5	7	9	11	13	15
$b_n =$	+0.612	+0.606	−0 2485	−0.702	+0.0976	−0.030	+0.0249	−0.0202
$a_n =$	−3.89	+0.014	+0.345	−0.195	+0.0528	+0.020	−0.015	−0.004

19. *The Dissipated Energy (Numerical).* By virtue of equations (**28**), (**29**) and (**30**), we have for the loss

$$L = \frac{V}{2\pi} \int_0^{\beta h} (-D_1 + D_2)\, d\beta \tag{31}$$

In forming the difference $(-D_1 + D_2)$ all sine members disappear and we get

$$\frac{L}{V} = -10^{-3} \times \frac{2}{\pi^2} S^2 \times \lambda = -194100 \text{ ergs per cu. cm.} \tag{32}$$

wherein

$$\lambda = \left[\sum \frac{\text{const}}{n} \sin n \frac{\pi}{2} \frac{\beta}{S}\right]_0^{\beta h} = 3.7423 \tag{33}$$

β_h = approx. 13183; S = 16000

$n = 1, 2, 3 \; . \; . \; . \; . \; 15$

The only dimensional quantity on the right side of formula (**32**) is S^2 whose dimension in the $C\,G\,S$— system is $(C^{-1/2}\, G^{1/2}\, S^{-1})^2 = C^{-1}\, G\, S^{-2}$ = ergrs. per cu. cm., what it ought to be. In that way we get a confirmation that our theory and results are right.

According to the well-known Steinmetz formula, the hysteresis loss is computed by

$$\eta \times B_{max}^{1.6} \text{ in ergs per cu. cm.} \tag{34}$$

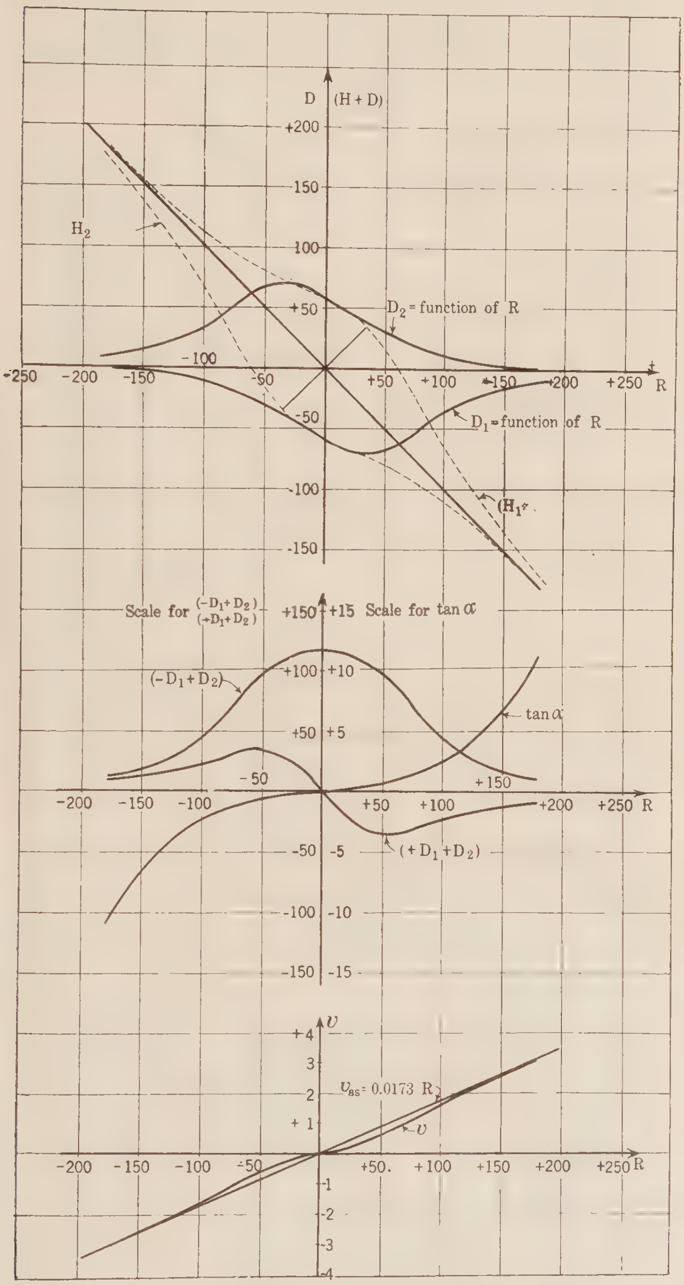
2. See *Electrotechnische Zeitschrift*, 1905. p. 247. C. Runge. "*Theorie & Praxis der Reihen*" Goshen at Leipsig, Germany.

which, when compared with our results, will ultimately net $\left(\text{neglecting } \frac{H_h}{S} = 0.011\right)$:—

$$\eta = 0.04862$$

and

$$\lambda = \frac{1000\,\eta \times \pi^2}{2}\left(\frac{\beta_h}{S}\right)^{1\cdot 6} \times S^{-2/5} \qquad (36)$$



FIGS. 9–10–11

Further experiments should show to what extent this formula is correct.

Appendix III contains formulas which give the energy loss in explicit terms of the leading quantities.

20. *Magnetic Friction D as Function of Magnetic Tension.* Fig. 9 shows curves. For formulas see Appendix III.

21. *Loss of Energy in Terms of Flux β and Tension R.* Formulas and computations will be found in Appendix III. Pertinent curves are illustrated below Figs. 9, 10, 11.

VI. ALTERNATING CURRENT EXCITATION

23. *Sine Current.* In the case where an alternating current is used to furnish the magnetomotive force, the intensity of the magnetic field will be expressed by

$$H = H_h \times \sin\frac{2\,\pi}{T}t = \text{const} \times I_0 \sin\frac{2\,\pi}{T}t \qquad (37)$$

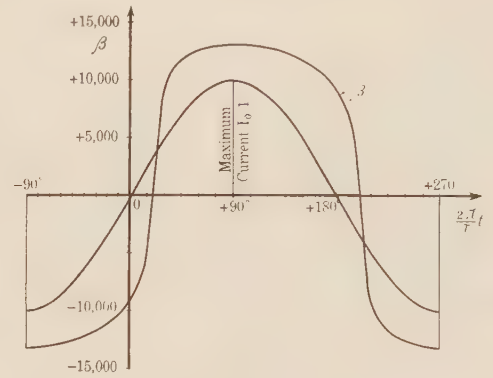


FIG. 12

while the curve for β contains higher harmonics as per Fig. 12 (for the sample tested).

$$\beta = S \times \sum c_n \sin\left(\frac{2\,\pi}{T}t + \omega_n\right) \qquad (39)$$

with

n =	1	3	5	7	9	11
c_n =	+0.9482	+0.2324	+0.1212	+0.07891	+0.05684	+0.09989
ω_n =	−8°26′	−61°7′	−106°28.4′	−151°48.6′	+163°3.6′	−102°23.6′

24. *Sine Voltage.* For the case of a sine voltage

$$E = E_0 \sin\frac{2\,\pi}{T}t$$

being applied to the windings around the magnetic material, the magnetic flux β and field H are illustrated in Fig. 13.

$$\beta = S \times \sum C_n \sin\left(\frac{2\,\pi}{T}t + \Omega_n\right) \qquad (41)$$

with

n =	1	3	5	7	9	11
C_n =	+0.8314	$+\frac{2.868}{1000}$	$+\frac{0.6956}{1000}$	$+\frac{0.069}{1000}$	$+\frac{0.08924}{1000}$	$+\frac{0.5953}{1000}$
Ω_n =	−90°14.8′	+82°35′	+60°37.9′	+94°56′	+176°0′	−161°38.4′

and

$$H = 177 \sum h_n \sin\left(\frac{2\,\pi}{T}t + \nu_n\right) \qquad (42)$$

with

n =	1	3	5	7	9	11
h_n =	+0.7559	−0.2592	−0.0629	−0.00624	−0.00806	−0.00538
ν_n =	−64°43.7′	+82°35′	+60°37.9′	+94°56′	+176°0′	−161°38.4′

VII. Applying the Theory

To show the ability of the new theory we shall now apply it to the well-known theory of Hopkinson's Magnetic Circuit, in conjunction with Professor Kennelly's paper on Reluctivity (Transactions of the A. I. E. E. 1891, page 485.)

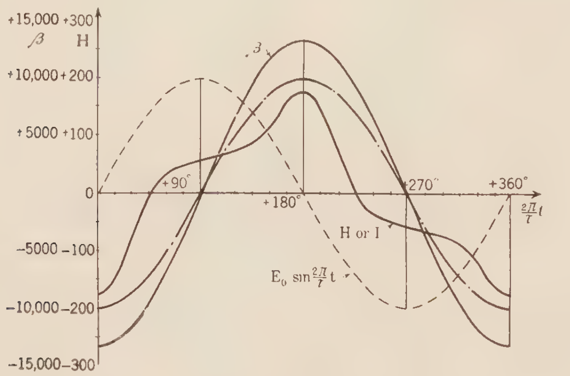


Fig. 13

In said paper (Figs. 4 and 5) the rectilinear characteristic of the metallic reluctivity $\rho = \dfrac{1}{4\,\pi\,\kappa}$ when plotted against H is particularly stressed.

With the results of our theory conceded, calling for internal reactive forces R and D, *only that part* of H which is equal $-R$ remains available for magnetization proper. If ρ be therefore related to $-R$, instead of H, we get for the metallic reluctivity

$$\rho = \frac{1}{4\,\pi\,\kappa} = \frac{-R}{\beta} = \frac{-R}{\mp S}\,e^{\phi}$$

use $-S$ when R = positive
use $+S$ when R = negative

and for the apparent reluctivity

$$r = \frac{1}{\mu} = \frac{\rho}{1+\rho}$$

both of which are illustrated in Fig. 14 at two different scales for our sample of hardened Tungsten Steel.

We note particularly that for large values of $R-$ (which differ only slightly from corresponding values of H) ρ is very nearly a straight line whose asymptote runs through the origin of the system at an inclination

$$\tan\tau = \frac{1}{S},\text{ which in our case } \frac{1}{16000} = 0.0000625.$$

It is of the same order as the gradient of right hand end of curve for "Glass Hard Pianoforte Steel, Ewing 1890," given in Fig. 5 of Professor Kennelly's paper. The straight lines (substitutes for curves) in said Fig. 5 do, however, not run through origin, because those curves are plotted against H, which includes the component opposing D.

Even diamagnetism may be explained now, by reversing in above formula for ρ the sign of R. That is permissible from the mathematical standpoint and conceivable from the physical standpoint so long as β in Fig. 4 remains between the limits $+S$ and $-S$. Reversal of sign of R takes place automatically when $\beta > S$, but such a condition cannot be reconciled with our definition of S as a maximum value of β.

Notations and Symbols Used in This Paper

B Induction or flux density
H Magnetizing force; also spatial induction
β Intrinsic induction (*i. e.*, $B - H$)
S Saturation value, that is the limiting value of β
γ Capacity for further induction (*i. e.*, $S - \beta$)
R Reactive component of internal force, opposing magnetization in either direction.
D Dissipative component of the internal force, opposing all changes of induction β.
M Maximum value of $(-D_1 + D_2)$
Subscript$_1$ indicates appertainment to ascending branch of hysteresis loop
Subscript$_2$ indicates appertainment to descending branch of hysteresis loop
Subscript$_h$ indicates highest vaule attained

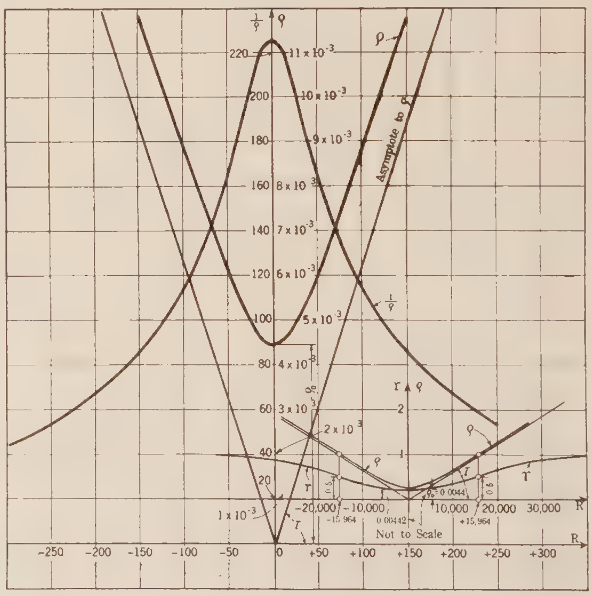


Fig. 14

Subscript$_0$ indicates that a related quantity has zero value
θ = $u + \varphi$, a hyperbolic angle
α = a circular angle
v = a hyperbolic angle

The unit for quantities B, H, β, S, γ, R, D, M in the $C\,G\,S-$ system is $C^{-1/2}\,G^{1/2}\,S^{-1}$ that is the Gauss = Number of lines of force per square centimeter.
L = Energy Loss in ergs ($C^2\,G\,S^{-2}$).
1.356×10^7 ergs = 1 ft-lb.

For illustration of leading symbols see Figs. 1 to 4.

Steady-State Stability in Transmission Systems
Calculation by Means of Equivalent Circuits or Circle Diagrams

BY EDITH CLARKE[1]

Associate, A. I. E. E.

Synopsis.—*The maximum load on a proposed transmission system must be within the steady-state power limit of the system for stability of operation. Two methods of calculating steady state stability are given in detail and illustrated by examples. (1) The given transmission system is replaced by a simple equivalent system, then the steady-state power limit of this equivalent system is determined graphically. (2) By means of a circle diagram the system is tested for stability with the maximum proposed load on the system.*

All formulas from published references necessary for the calculations are included and all calculations are given in full so that similar studies can readily be made by an engineer who has not previously made a study of the subject of stability.

The object of this paper is to give two methods of determining the stability of operation of a proposed transmission system under steady-state conditions. The calculations will be given in detail so that the engineer who has not previously made a study of the subject will have no difficulty in applying the tests for stability to his system. The first method is by means of an equivalent circuit and the second by means of a circle diagram. Both methods are based on theorems which are exact, but in order to fit the transmission system to the theorems certain assumptions must be made. The results will therefore be approximate to the extent to which the assumptions approximate actual conditions.

Formerly when a transmission system was proposed, it was customary to make the line calculations for voltage regulation and losses for the maximum load conditions, and to select the generators, transformers and synchronous condensers to fit these conditions. There was nothing in such calculations to indicate that the system would be stable, but fortunately the length of line and maximum load have been such that cases of instability have been rare. At the present time when the tendency is for longer lines and greater loads, it is necessary to consider the question of stability both for steady state and transient conditions. Steady-state stability only will be considered in this paper.

In steady-state stability the assumption is made that the load comes on in infinitesimal amounts so that the transient caused by one increment is over before the next increment is added. The criterion of steady-state stability is this: Assuming that the system is operating satisfactorily under the assumed load conditions, will it continue to operate satisfactorily if an increment of synchronous load is added and all excitations remain constant? When load is added there is an increase in current and a drop in voltage before there is any change in excitation. The voltage regulators then increase the excitations and normal voltage is obtained. If the load on the system is *just* the amount which can be transmitted at excitations which correspond to normal voltage, any increase in synchronous load will cause instability because the voltage must drop before the voltage regulators can increase the excitations and at the given excitations no more power can be transmitted. Therefore, when the voltage starts to drop it will continue to drop, for there is no voltage at which the load can be transmitted with those excitations.

When a generator and motor are on the same bus, at no-load, neglecting no-load losses, their induced voltages are in phase. Keeping the excitations on motor and generator constant as the motor is gradually loaded, the phase displacement between the excitation voltages of motor and generator increases with load until the machines fall out of step. The load at which the machines fall out of step is the maximum load and the angle is the maximum power angle. This angle and the power corresponding to it can be calculated. Power corresponding to an angle greater than the maximum power angle can also be calculated although it cannot be delivered.

In the simple transmission system consisting of a synchronous generator supplying power to a synchronous motor over a line having resistance and reactance, but no appreciable capacitance or leakance, the maximum power that can be transmitted over the system, and the angle between the generator and motor excitation voltages corresponding to maximum power, are not difficult to calculate. This simple system will be stable under a proposed load if the phase displacement between the synchronous generator and synchronous motor excitation voltages corresponding to the proposed load is less than the phase displacement which corresponds to maximum power on the shaft of the motor. When a transmission system consisting of generators, lines with distributed constants, and the usual station load can be replaced by the simple transmission system, the maximum power that can be transmitted over the system is easily calculated. In studying steady-state stability by means of equivalent circuits an attempt is made to replace the complicated transmission system by the equivalent simple system.

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1. Central Station Engineering Dept., General Electric Co.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, Feb. 8-11, 1926. Complete copies available upon request.

Equivalent Line

Dr. E. A. Kennelly[2] has shown that a line with distributed constants can be replaced by either an equivalent π or T line in which the constants are lumped. The π line consists of a line with a shunt at each end and the T line of a line with a shunt at the center. The nominal π is formed by placing the total impedance, Z, of the actual line in the line or architrave of the π and one-half the admittance, Y, in each shunt or pillar. The nominal T is formed by placing one-half the total impedance of the actual line in each arm of the T and the total admittance in the shunt or staff. The nominal π and T lines are not exact equivalents of the actual line, but by applying correcting factors to them the equivalent π and T lines are obtained which are exact equivalents of the actual line.

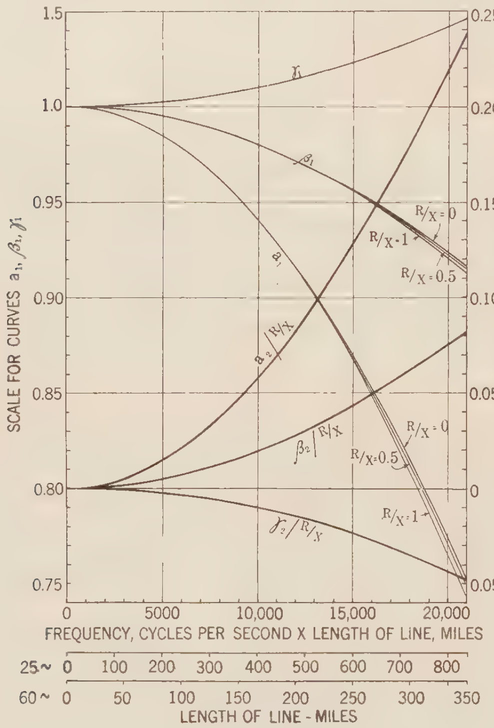

Fig. 1—Complex Hyperbolic Functions

$$\cosh \sqrt{Z Y} = 1 + \frac{Z Y}{2} + \ldots = a_1 + j\, a_2$$

$$\frac{\sinh \sqrt{Z Y}}{\sqrt{Z Y}} = 1 + \frac{Z Y}{2} + \ldots = \beta_1 + \beta_2$$

$$\frac{\tanh \sqrt{Z Y/2}}{\sqrt{Z Y/2}} = \gamma_1 + j\, \gamma_2$$

Correcting Factors for Converting the Nominal π or T Line Into the Equivalent π or T. The correcting factors which must be applied to convert the nominal π or T into the equivalent π or T are $\dfrac{\sinh \sqrt{Z Y}}{\sqrt{Z Y}}$ to be applied to the architrave of the π and the staff of the T and $\dfrac{\tanh (\sqrt{Z Y/2})}{\sqrt{Z Y/2}}$ to be applied to the pillars of the π and the arms of the T.

2. "Application of Hyperbolic Functions to Electric Engineering Problems."

Fig. 1 gives the real and imaginary parts of these correcting factors. For convenience the real and imaginary parts of cosh $\sqrt{Z Y}$ are also given.

Power at a Point Within the Equivalent π. The π-line viewed from either end is an exact equivalent of the line with distributed constants but the current and voltage at any point in the architrave of the π do not correspond to current and voltage on the actual line. Let the π-line in Fig. 2 be the equivalent π of the line $A\ B$ with distributed constants. Although the current at d is the same as the current at B, the current at c has no counterpart in the actual line. The power at d is the same as the power at B, but the power at c is the power at d plus the power lost in shunt Z_4. When the power is known at b and c it can be calculated at a and d.

Synchronous Impedance

It is understood that the synchronous impedance of a synchronous generator or motor is not constant. However, given the characteristics of the machine and the conditions of operation, it is possible to find an *equivalent* synchronous impedance which may be considered constant for the case under consideration. In the work which follows constant synchronous impedance refers to this equivalent synchronous impedance.

For the synchronous condenser it is necessary to find an equivalent excitation as well as an equivalent synchronous impedance. This is discussed at greater length in Appendix E.

Equivalent Generator

If a system consist of a synchronous generator and synchronous motor, both of constant synchronous impedance, connected by a line with a shunt at the generator end, this system can be replaced for all points beyond the shunt by a system unchanged beyond the shunt, but having a new generator whose impedance is the impedance of the generator and shunt in parallel and whose excitation voltage

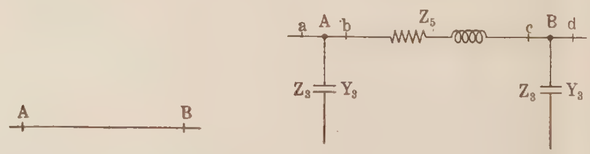

Fig. 2—A. Line $A\ B$ with Distributed constants
B. Equivalent π = Line

$E_1{}' = E_1 \dfrac{Z_1 Z_s}{Z_1 + Z_s} / Z_1 = E_1 \dfrac{Z_s}{Z_1 + Z_s}$, where E_1 is the actual generator excitation voltage, Z_1 is the generator impedance and Z_s is the shunt impedance.

This will be an exact equivalent, for the power at breakdown on the two systems will be same. The proof is given in Appendix C (b).

Equivalent Motor

If a system consist of a synchronous generator and synchronous motor, both of constant synchronous

impedance, connected by a line with a shunt at the motor end this system can be replaced for all points in front of the shunt by a system unchanged up to the shunt, but having a new motor whose impedance is the impedance of the motor and shunt in parallel and whose excitation voltage $E_2' = E_2 \dfrac{Z_2 Z_s}{Z_2 + Z_s} / Z_2 = E_2 \dfrac{Z_s}{Z_2 + Z_s}$, where E_2 is the actual motor excitation voltage, Z_2 is the motor impedance and Z_s is the shunt impedance; but power on the fictitious system corresponding to breakdown power on the actual system occurs when the phase displacement between the generator and equivalent motor excitation voltages is the total impedance angle of the fictitious system plus the angle, $2(\theta_2 - \theta_2')$, where θ_2 is the impedance angle of the actual motor and θ_2' is the impedance angle of the equivalent motor. The proof is given in Appendix C (*b*).

Equivalent System and Voltage Regulators

If a system consists of a synchronous generator and synchronous motor, both of constant synchronous impedance, connected by a line with a shunt at each end, voltage being maintained at the ends of the line, this system can be replaced for all points of the line by a system consisting of the same line without shunts, a generator whose impedance is the impedance of the actual generator and shunt at the generator end in parallel and a motor whose impedance is the impedance of the actual motor and shunt at the motor end in parallel; but power on the fictitious system corresponding to breakdown power on the actual system occurs when the phase displacement between equivalent motor and generator excitation voltages is the total impedance angle of the fictitious system plus $2(\theta_2 - \theta_2')$ where θ_2 is the impedance angle of the actual motor and θ_2' the impedance angle of the equivalent motor. The proof is given in Appendix D.

When $2(\theta_2 - \theta_2') = 0$ deg., the fictitious system becomes an equivalent system, for the power at breakdown on the two systems will be the same. When resistance is neglected in the motor and motor end shunt $2(\theta_2 - \theta_2') = 0$ deg. or 360 deg.

Since no limitation is placed on the shunt impedances in the proofs given in the appendix, in addition to representing the capacitance in the line, they may represent reactors, resistance load or any other dead load.

Equivalent Circuit Method

Graphical Solution. When the actual system has been replaced by the equivalent simple system, the maximum power which can be transmitted may be obtained graphically.

Let Fig. 3A represent the simple equivalent system, where

$Z_5 = r + jx =$ the impedance of the equivalent line.

$Z_1 = r_1 + jx_1 =$ the actual generator impedance.

$Z_1' = r_1' + jx_1 =$ the equivalent generator impedance formed by taking the shunts at the generator end of the line in parallel with the generator impedance.

$Z_2 = r_2 + jx_2 =$ the actual motor impedance.

$Z_2' = r_2' + jx_2' =$ the equivalent motor impedance formed by taking the shunts at the motor end of the line in parallel with the motor impedance.

$E_1 =$ excitation voltage of the actual generator.

$E_2 =$ excitation voltage of the actual motor.

$E_1' =$ excitation voltage of the equivalent generator $= E_1 \dfrac{Z_1'}{Z_1}$

$E_2' =$ excitation voltage of the equivalent motor $= E_2 \dfrac{Z_2'}{Z_2}$

$E_A =$ terminal voltage at the generator end of the line.

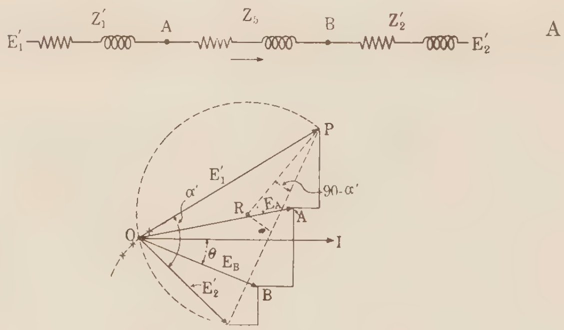

Fig. 3—A. Equivalent Transmission System
B. Graphical Determination of Maximum Power Over the Equivalent Transmission System

$E_B =$ terminal voltage at the receiver end of the line.

$Z_t = (r + jx + r_1' + jx_1' + r_2' + jx_2') = R_t + jX_t$
$= z_t\, e^{j\theta_t}$
$=$ total impedance of the equivalent system.

$\theta_t = \tan^{-1} \dfrac{X_t}{R_t} =$ total impedance angle.

$\theta_2 = \tan^{-1} \dfrac{x_2}{r_2} =$ impedance angle of the actual motor.

$\theta_2' = \tan^{-1} \dfrac{x_2'}{r_2'}$ impedance angle of the equivalent motor.

Calculate $\alpha' = \theta_t + 2(\theta_2 - \theta_2')$

Since there are no shunts in the equivalent or fictitious system the same current will flow in all parts of the circuit. Taking current as standard phase, lay off

$QBAP = I(r_2' + jx_2') + I(r + jx) + I(r_1' + jx_1')$

to any convenient scale. Fig. 3B. The value of this scale will be determined when the construction has been completed and the position of point O determined.

There are two conditions which determined the position of point O.

1. $\alpha' = \theta_t + 2(\theta_2 - \theta_2')$

2. The ratio between the magnitudes of E_A and E_B or between E_1' and E_2' is known. For a regulated line E_A and E_B are given, and for a line without voltage regulators E_1' and E_2' can be calculated from the known values E_1 and E_2.

Consider the case of the regulated line: To satisfy the first condition join P and Q and at P drawn PR making an angle, $(90° - \alpha')$ with PQ. With R, the intersection of PR with the perpendicular bisector of PQ, as a center and RP as radius describe arc PQ. If point O lies on this arc, the first condition will be satisfied. To satisfy the second condition, find a series of points whose distances from A and B are in the ratio E_A/E_B and draw a curve through them. O will lie on the intersection of this curve with the arc PQ.

The scale of the vector diagram is determined, for $OB = E_B$. All voltage drops are now given in terms of E_B. E_B is known, therefore all voltage drops are known and the current can be calculated. The power factor angle, θ, can be measured.

Maximum Power at $B = E_B \,.\, I \,.\, \cos\theta$.

The impedances, voltages and currents may be expressed in ohms, volts and amperes respectively or in per cent, as is most convenient.

Algebraic Solution—Resistance Neglected. When resistance is neglected and equal voltages are maintained at the ends of the line a simple formula can be derived for the power delivered.

If

X_1' = the equivalent generator reactance.

X_2' = the equivalent motor reactance.

X = the equivalent line reactance.

V_A = V_B = magnitude of line terminal voltages, E_A and E_B.

$$P_{max} = \frac{V_B^2\sqrt{\left(X_1' + \frac{X}{2}\right)\left(X_2' + \frac{X}{2}\right)}}{\left(\frac{X}{2}\right)^2 + \left(X_1' + \frac{X}{2}\right)\left(X_2' + \frac{X}{2}\right)} \qquad (1)^*$$

When V_B is in volts to neutral, and reactances are in ohms, power will be in watts per phase. If voltages and reactances are in per cent, power will be in per cent (20% = 0.20).

When V_B = 100 per cent and the motor and generator have the same impedance ($X_1' = X_2'$), equation (1) becomes

$$P_{max} = \frac{X_1' + \frac{X}{2}}{\left(\frac{X}{2}\right)^2 + \left(X_1' + \frac{X}{2}\right)^2} \qquad (2)$$

*This equation was first developed by C. A. Nickle.

When $X = O$, which is the case for a motor and generator on the same bus,

$$P_{max} = \frac{1}{X_1'} \qquad (3)$$

When $X_1' = X_2' = O$, which is the case for infinite busses at the ends of the line,

$$P_{max} = \frac{1}{X} \qquad (4)$$

Application of the Fictitious or Equivalent System to Steady State Stability Problems

1. *Effect of Capacitance in the Line.* If resistance is neglected and generator and motor of equal impedances are assumed, equation (2) may be used to calculate maximum power over the line with and without capacitance. Without capacitance, X_1' will be the actual generator impedance. Capacitance in the line

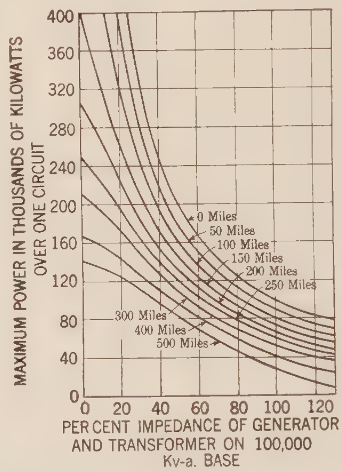

Fig. 5—Maximum Synchronous Load Delivered over 220-Kv., 60 Cycle, Transmission Lines of Various Lengths

When resistance is neglected. Synchronous generators and motors assumed to have equal synchronous impedances. (Transformer impedance included in generator impedance)

will reduce X, since X is multiplied by the correcting factor β which is less than unity, but it will increase X_1', for when the negative reactances of the shunts of the equivalent π-line are combined in parallel with the positive reactances of the machines, the equivalent reactances are greater than the actual machine reactances. The effect of capacitance will be to increase or decrease the maximum power depending upon whether the change in X or in X_1' has the greater influence.

Curves for Estimating Maximum Power

The curves in Fig. 5 were calculated for 60 cycles and various lengths of line, assuming reactance of 0.813 mhos per mile and capacity susceptance of 5.22×10^{-6} mhos per mile, 220 kv. was maintained at each end of the line, resistance was neglected in the line and in the generators and motors which were assumed of equal synchronous impedances. These curves can be used as a first approximation.

2. *Reactor Across the Generator Terminals.* If a reactor is placed across the generator terminals the effect is opposite to the effect produced by the capacity shunt. The reactor reduces the equivalent generator impedance so that more power can be transmitted over the system. It must be remembered that the excitation on the generator is increased by the use of a reactor, but when full field is not being used on the generator, a reactor increases the power that can be transmitted by the same amount that a generator of the same rating would do. Since reactors are cheaper than generators, a reactor of the size that would put full excitation on the generator can be used to advantage to increase the stability of the system.

3. *Power Limits of a Long Line.*

a. Limit of the line alone.
b. Limit of the line and transformers.
c. Limit of the line transformers and generator.
d. Limit of the system with various kinds of load.
   1. Synchronous motors.
   2. Lights and synchronous motors.
   3. Lights, induction motors, synchronous motors and synchronous condensers.
   4. Same as (3) but with a generator supplying local load.

A line with generator and transformers will be selected then the maximum power will be obtained for the specified conditions.

Given:

A three phase, 60 cycle, 250 mile line.

Line constants: r = 0.151 ohms per mile
x = 0.813 ohms per mile
y = 5.22 micro-mhos per mile
Leakance = O.

Step-up transformers: 270,000 kv-a. total
2 per cent resistance
12 per cent reactance
13,200—220,000 volts.

Step-down transformers: 240,000 kv-a. total,
2 per cent resistance
12 per cent reactance
210,000-13,200 volts

Generators: 270,000 kv-a. total
0.9 power factor, 13,200 volts
100 per cent synchronous impedance.

Voltage regulators will maintain 220 kv. and 200 kv. at the generator and receiver ends respectively on the low sides of the transformers (assuming a one-to-one ratio of transformation). The magnetizing current in the transformers will be neglected.

From equation (7) Appendix C (a).

$$P_{max} = \frac{V_1 V_2}{z} \left(1 - \frac{V_2}{V_1} \cos \theta\right), \text{ where } V_1 \text{ and } V_2$$

are terminal voltages at the generator and receiver ends respectively, Z is total impedance, and θ is total impedance angle.

When V_1 and V_2 are in volts to neutral and Z is in ohms, power will be in watts per phase. If voltages and impedances are in per cent, power will be in per cent (20 per cent = 0.20).

When V_1 and V_2 are bus voltages, Z the total impedance between the buses and θ the total impedance angle, P_{max} will be the maximum power that can be exchanged between the buses.

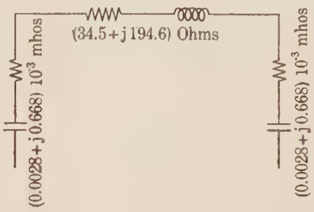

FIG. 6—EQUIVALENT π OF THE TRANSMISSION LINE ALONE

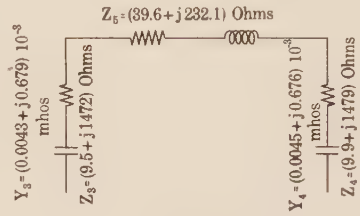

FIG. 9—EQUIVALENT π OF THE LINE AND TRANSFORMERS

When V_1 and V_2 are excitation voltages of synchronous generator and synchronous motor respectively, Z the total impedance between them and θ the total impedance angle, P_{max} will be the synchronizing power between the two machines.

Fig. 6 gives the equivalent π of the line alone. Fig. 9 gives the equivalent π of the line and transformers.

The maximum power which can be transmitted over the line alone and over the line with transformers may be obtained by subtracting the power lost in the receiver shunt from the total power which can be exchanged between the buses.

(a) The limit of the line alone = 187,000 kw.

(b) The limit of the line with transformers = 158,500 kv.

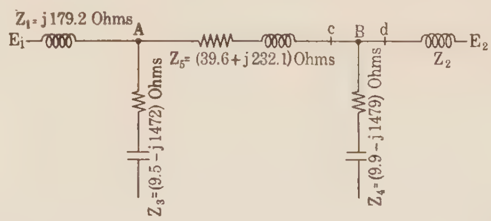

FIG. 11—EQUIVALENT π OF THE LINE AND TRANSFORMERS

With synchronous generator and motor. Impedances are in ohms referred to the high side.

(c) Limit of the line, transformers and generator is obtained by assuming a motor of zero impedance or an infinite bus at the receiver end.

Fig. 11 represents the line with end shunts and a motor and generator each of constant synchronous impedance. The power at d, that is the power de-

livered to the load, will be the power at c minus the power lost in Z_4. Fig. 12 gives the equivalent circuit with the impedances in per cent on a 100,000 kv-a. base. 100 per cent voltage = 200 kv. The shunt Z_3 has been combined in parallel with the generator impedance. The shunt Z_3 has not been combined with the motor impedance.

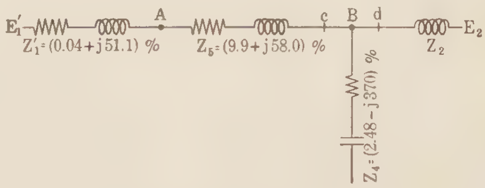

FIG. 12—EQUIVALENT CIRCUIT OF LINE, TRANSFORMERS, GENERATOR AND MOTOR

Impedances are in per cent on a 100,000-kv-a. base. 100 per cent voltage = 200 kv.

The voltages and impedances in per cent from Fig. 12 are

E_A = 110 per cent, E_B = 100 per cent,

$Z_1' = (0.04 + j\,51.1)$ per cent, $Z_2' = O$

$Z_5 = (9.9 + j\,58.0)$ per cent,

$Z_5 + Z_1' + Z_2' = (9.9 + j\,109.1)$ per cent $= Z_t$

α' = maximum power angle $= \theta_t + 2\,(\theta_2 - \theta_2') = \theta_t$

$$= \tan^{-1}\frac{109.1}{9.94} = 84.7 \text{ deg.}$$

Making the graphical construction as described above, Fig. 13 is obtained. From Fig. 13

Since $O\,B$ = 100 per cent Voltage, $I = \dfrac{\overline{B\,P}}{\overline{O\,B}}\,/_{zt}$

$$= \frac{1.845}{1.095} = 1.685 = 168.5 \text{ per cent current.}$$

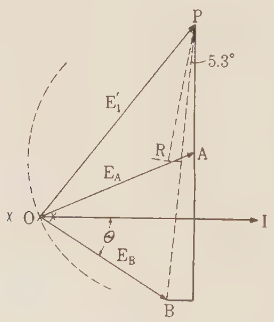

FIG. 13—GRAPHICAL DETERMINATION OF MAXIMUM POWER WITH AN INFINITE BUS AT THE RECEIVER END

Power factor at B = 0.84 lead.

Power at c = $1 \times 1.685 \times 0.84 = 1.415$

= 141.5 per cent on 100,000 kv-a. base

= 141,500 kw.

Power lost in shunt Z_4 = 180 kw.

Limit of the line, transformers and generators = 141,300 kw.

d. Limit of the system with various kinds of load.

1. Synchronous motor load of total capacity 170,000 kv-a., 85 per cent synchronous impedance.

Z_2 = motor impedance on 100,000 kv-a. base = 50 per cent

$Z_2' = \dfrac{Z_2\,Z_4}{Z_2 + Z_4}$ = impedance of equivalent motor

$= (0.07 + j\,57.8)$ per cent

Fig. 14 gives the equivalent circuit.

Z_t = total impedance = $(10.0 + j\,166.9)$ per cent.

θ_t = total impedance angle = 86.6 deg.

θ_2 = impedance angle of actual motor = 90 deg.

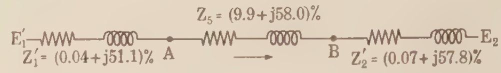

FIG. 14—EQUIVALENT CIRCUIT FOR SYNCHRONOUS MOTOR LOAD

θ_2' = impedance angle of equivalent motor = 89.9 deg.

$2\,(\theta_2 - \theta_2') = 0.2$ deg.

$\alpha' = \theta_t + 2\,(\theta_2 - \theta_2') = 86.7$ deg.

Using the equivalent circuit given in Fig 14 and. making the graphical construction as described above, Fig. 15 is obtained.

Since $O\,B$ = 100 per cent voltage, I = 112.5 per cent current and

Power factor at B = 0.943 lead.

Power at c = $1 \times 1.125 \times 0.943 = 1.06$

= 106,000 kw.

Power lost in shunt Z_4 = 180 kw.

Maximum power that can be delivered to the load = 106,000 kw.

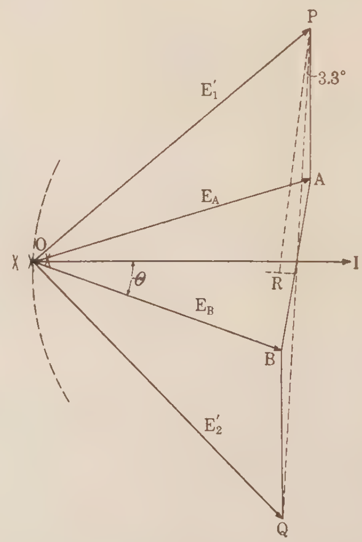

FIG. 15—GRAPHICAL DETERMINATION OF MAXIMUM POWER FOR A SYNCHRONOUS MOTOR LOAD

2. Resistance load of 30,000 kw., synchronous motors of total capacity 170,000 kv-a. with 85 per cent synchronous impedance.

R = resistance of the resistance load shunt.

= 1333 ohms.

= 333.3 per cent on 100,000 kv-a.; base, 200 kv.

Z_4' = impedance of Z_4 and R in parallel = $(184 - j\,165)$ per cent

Z_2 = impedance of actual motor = 50 per cent

$Z_2' = \dfrac{Z_2 Z_4'}{Z_2 + Z_4'}$ = impedance of equivalent motor $= (9.8 + j\,56.1)$ per cent

Z_t = total impedance of equivalent circuit $= (19.74 + j\,165.2)$ per cent

θ_t = 83.2 deg. = total impedance angle.

$\alpha' = \theta_t + 2(\theta_2 - \theta_2') = 83.2\text{deg.} + 2\,(90 - 80.1\text{deg.}) = 103.0$ deg.

The graphical construction is given in Fig. 16.

Since $O\,B$ = 100 per cent

I = 138.5 per cent and power factor at B = 0.90 lead

Power at c $= 1 \times 1.385 \times 0.90 = 1.248$ = 124,800 kw.

Power lost in the line shunt Z_4 = 180 kw.

Maximum power that can be delivered to the load = 124,600 kw.

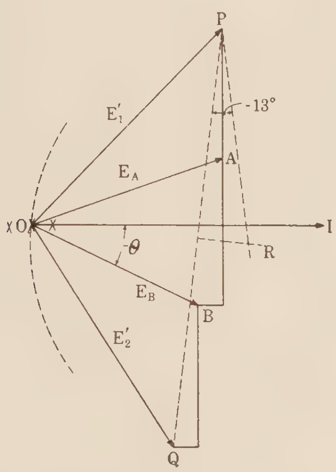

FIG. 16—GRAPHICAL DETERMINATION OF MAXIMUM POWER FOR A LOAD PARTLY RESISTANCE AND PARTLY SYNCHRONOUS

3. Lights, induction motors, synchronous motors and synchronous condensers.

4. Same as (3) but with generator supplying local load.

As voltage drops on an induction motor load, the power required by the load remains practically constant and the power factor becomes less lagging. A lightly loaded synchronous motor has the same characteristics. The induction motor load therefore, may be replaced by an approximately equivalent synchronous motor.

A method of treating the synchronous condenser in the equivalent circuit is given in Appendix E.

Examples of type (3) can be solved by the equivalent circuit method but the solution with the circle diagram is more satisfactory than the solution by the equivalent circuit method available at present. An example of type (4) is solved by the circle diagram method. See example (3) following. It is hoped that systems more complicated than the one considered here as well as examples of types (3) and (4), will eventually be completely represented by equivalent circuits.

CIRCLE DIAGRAM METHOD

The test for stability by this method is to assume a slight increase in load and to determine if by a drop in receiver voltage this new load can be carried with the excitations corresponding to the original load.

When a system is operating at normal voltage and a load is added there is an increase in current at the receiver end and a drop in voltage. The power given to the additional load comes from the change in phase displacement between the sending and receiving end equipment. Due to the drop in voltage at the load, the original load does not require the same power it required at normal voltage if it is the average station load. The kw. and kv-a. taken by the original load changes with voltage. If voltage slightly less than normal is assumed at the receiver end and the kw. and kv-a. corresponding to the original load at this voltage plus a small load increment can be transmitted over the line with the given generator excitation, the system is stable, for the small increment is the contribution to the additional load made by the change in phase displacement of the system. For the limit of stability this increment approaches zero.

The method of obtaining the general circuit constants of a transmission system, and the construction of the power circle diagram from these constants has been described by Mr. R. D. Evans and Mr. H. K. Sels in a paper[4] before the Institute.

GENERAL CIRCUIT CONSTANTS

The same line, transformers and generator used to illustrate the equivalent circuit method will be used for the circle diagram.

The constants of the line alone are:

$$A = D = \cosh \sqrt{Y\,Z} = a_1 + j\,a_2 = 0.8700 + j\,0.0236$$

$$B = Z\,\frac{\sinh \sqrt{Z\,Y}}{\sqrt{Z\,Y}} = Z\,(\beta_1 + j\,\beta_2) = 34.52 + j\,194.6$$

$$C = Y\,\frac{\sinh \sqrt{Z\,Y}}{\sqrt{Z\,Y}} = Y\,(\beta_1 + j\,\beta_2)$$

$$= (-\,0.0104 + j\,1.248)\,10^{-3}$$

(a_1, a_2, β_1 and β_2 obtained from Fig. 1.)

The circuit constants of the line and the step-up and step-down transformers, neglecting magnetizing current, are calculated from *Item* (*g*) of the Evans and Sels paper.[5] To include magnetizing current *Item* (*j*) should be used instead of (*g*).

$A_0 = A + C\,Z_s = 0.8431 + j\,0.0279$

$B_0 = B + A\,(Z_s + Z_r) + C\,Z_s\,Z_r = 39.6 + j\,232.1$

$C_0 = C = (-\,0.0104 + j\,1.248)\,10^{-3}$

$D_o = A + C\,Z_z = 0.8424 + j\,0.0280$

Z_s and Z_r are the transformer impedances at the sending and receiving ends respectively.

4. Power Limitation of Transmission Systems, TRANSACTIONS of the A. I. E. E., Vol. 43, 1924, page 33.

It is of interest to note that these constants can be obtained from the equivalent π including the line and transformer or the equivalent π can be obtained from these constants. See Appendix F.

The circuit constants including the generator as well as the line and transformers are

$$A_{00} = A_0 + Z_1 C_0 = 0.6193 + j\,0.0260$$

$$B_{00} = Z_1 D_0 + B_0 = 34.59 + j\,383.1$$

Where A_0, B_0, C_0 and D_0 refer to the circuit constants of the line and transformers and Z_1 is the generator impedance.

Construction of the Circle Diagram

$$(P_R + l\,E_R^2)^2 + (Q_R + m\,E_R^2)^2 = n^2\,E_R^2\,E_s^2 *$$

is the equation of the Receiver Power Circle Diagram in volt-amperes. If the question is expressed in kilovolt amperes and divided by E_R^4 it becomes

$$\left(\frac{P_R}{E_R^2} + l\,10^3\right)^2 + \left(\frac{Q_R}{E_r^2} + m\,10^3\right)^2 = \left(n\,10^3\,\frac{E_s}{E_r}\right)^2$$

This is a circle for receiver power in terms of the receiver voltage and the ratio between the sending and receiving voltages. The center of the circle is at the point $-\,l\,10^3$, $-\,m\,10^3$.

If

$$A_0 = a_1 + j\,a_2$$

and

$$B_0 = R_0 + j\,X_0$$

$$l\,\dagger = \frac{a_1\,R_0 + a_2\,X_0}{R_0^2 + X_0^2}$$

$$m = \frac{a_1\,X_0 - a_2\,R_0}{R_0^2 + X_0^2}$$

$$n = \frac{1}{\sqrt{R_0^2 + X_0^2}}$$

Two circle diagrams will be drawn; one for the line and transformers and the other for the line, transformers and generator. Since they are both for power at the receiver end in terms or receiver end voltage, they will be drawn on the same chart. The ratio of the voltage on the low side of the transformer at the generator end to the voltage on the low side at the receiver end for normal operation has been assumed 220/200 = 1.1. One circle with E_s/E_r = 1.1 will be drawn in the diagram for the line and transformers. A series of circles with the ratio of the excitation voltage of the generator to the receiver voltage having various values will be drawn for the line, transformers and generator.

The problems already solved by means of the equivalent circuit will now be solved by the circle diagram.

b. The power limit of the line and transformers at the specified voltages is obtained from the dotted circle at the point where the tangent to the circle is vertical. At this point kw_r/kv_r^2 = 3.95, and $kw_r = 3.95 \times (200)^2$ = 158,000 kw.

c. The power limit of the generator, line and transformers is obtained from the dotted curve at the point where the tangent to the solid circle is vertical. At this point kw_r/kv_r^2 = 3.53, and $kw_r = 3.54 \times (200)^2$ = 141,200 kw.

The limit of the system with various kinds of load can not be determined directly by means of the circle diagram. A certain load must be assumed and then the system tested for stability with this load. If the system is stable, a larger load should be assumed, but if unstable, a test should be made with a smaller load. If this process is continued until a load is obtained for which the system is stable, but for which there is no margin, this will be the maximum power of the system.

To Test for Stability on the Circle Diagrams

Calculate kw_r/kv_r^2 for the given load at normal voltage and find the corresponding point on the dotted circle. The ratio of generator excitation voltage to receiver voltage is read from the solid circle cutting the dotted circle at this point, and the generator excitation voltage calculated. Assume a receiver voltage slightly less than normal and calculate the active and reactive power of the load corresponding to this voltage, assuming constants excitations. Divide the active and reactive power in kilovolt amperes by the square of the assumed receiver voltage in kilovolts and locate the point on the diagram. Read E_1/E_r at this point and calculate E_1, the generator excitation voltage. If this value of E_1 is equal to or less than the excitation voltage calculated at normal voltage the system is stable. It is sometimes more satisfactory to select a receiver voltage slightly above normal as well as one below normal, then when the corresponding calculated generator excitation voltages are both higher than the excitation voltage corresponding to normal receiver voltage, the assumed load is the power limit.

1. Given: 170,000 kv-a. synchronous motor, 85 per cent synchronous impedance.

It has been shown by the equivalent circuit method that 106,000 kw. is the maximum power that can be delivered to this motor. Testing by means of the circle diagram, Fig. 17, for a load of 106,000 kw., point A, located on the dotted circle for kw_r/kv_r^2 = 2.65, gives the generator excitation voltage from the solid circle passing through A as 242 kv. at normal receiver voltage. Point A' corresponds to 98 per cent receiver voltage and A'' to 102 per cent receiver voltage. The corresponding generator excitation voltage in each case is just about 242 kv. which indicates that 106,000 kw. is very near the limit of stability.

2. Given: Resistance load of 30,000 kw., and the synchronous motor of example 1.

The power delivered to a resistance load varies as the square of the voltage. The power delivered to a shaft load is practically independent of voltage. Points

*Equation (28) A. I. E. E. Transactions, Vol. 43, page 36.

†Circle Diagrams for Transmission Systems, R. D. Evans and H. K. Sels, *Electric Journal*, December 1921.

B, B' and B'' on the circle diagram give the generator excitation voltages corresponding to receiver voltages of 100 per cent, 98 per cent and 102 per cent respectively for a load of 120,000 kw., and points C, C' and C'' the corresponding values for a load of 130,000 kw. The system is stable at 120,000 kw. but unstable at 130,000 kw.

3. Given: Total load of 180,000 kw. of which one-third is resistance load, one-third induction motor load and one-third synchronous motor load. The induction motors have an average power factor of 0.7 lag at normal voltage. The synchronous motors have 100 per cent synchronous impedance, are 75 per cent loaded and are operated at unity power factor. A 100,000 kv-a. synchronous condenser is placed at the load. The generators at the receiver end of the line, having total capacity of 100,000 kv-a. and synchronous impedance of 100 per cent, supply 45,000 kw. to the load and part of the reactive kv-a. needed for voltage regulation. Is the system stable?

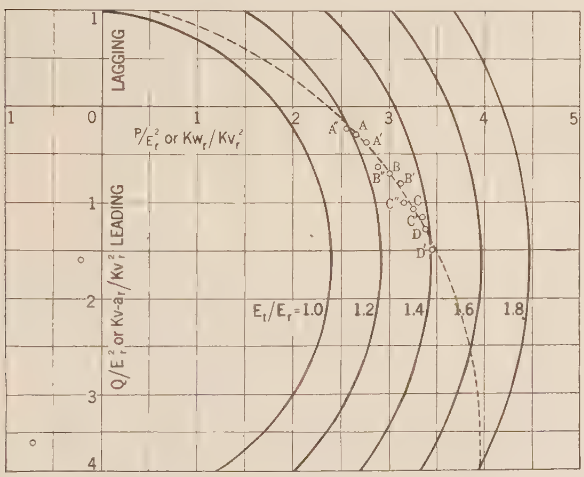

Fig. 17—Circle Diagram for the Transmission System

100 Per Cent Receiver Voltage

E_r = 200 kv. = 100 per cent receiver voltage.

P_r = 135,000 kw. = total power over the line.

$\dfrac{P_r}{E_r^2} = \dfrac{\text{kw}_r}{\text{kv}_r^2} = 3.375$, determines location of point D on dotted circle, Fig. 17.

$\dfrac{Q_r}{E_r^2}$ = 1.28 read at point D, Fig. 17.

Q_r = 51,200 kv-a. = total reactive power over the line.

E_1/E_r = 1.385, obtained from solid circle passing through D.

E_1 = 277 kv. = excitation voltage of generator at sending end.

98% Receiver Voltage.

E_r = 196 kv. = 98 per cent voltage

P_r = 132,600 kw.
Q_r = 57,270 kv-a.
} active and reactive power of the original load at 98 per cent receiver voltage and constant excitations.

$\dfrac{P_r + Q_r}{E_r^2} = 3.45 + j\,1.49$, determines location of point D'

E_1/E_r = 1.41, obtained from solid circle passing through D'.

E_1 = 276 kv., excitation voltage of generator at the sending end.

Since E_1, the calculated generator excitation voltage, at 98 per cent receiver voltage is less than E_1 at 100 per cent receiver voltage for the same receiver load, the system is stable. These calculations do not indicate the load which can be added with stability maintained. They merely indicate that the system is stable under the assumed load conditions.

In the examples which have been considered a single generating station supplies power over one circuit to a single receiving station. In more complicated systems where it may be necessary to cut and try, the circle diagram can be used to advantage for the various parts of the system.

Acknowledgment

The idea of combining the shunts at the ends of the line with the synchronous apparatus is due to Mr. C. A. Nickle who proved that "neglecting resistance, a line with synchronous apparatus and reactance or capacitance shunts may be replaced by a line and equivalent synchronous apparatus with no shunts."

The writer wishes gratefully to acknowledge her indebtedness to Messrs. H. H. Dewey and R. E. Doherty for their encouragement and suggestions which have broadened the scope of this study, and to Mr. Nickle for his suggestions in the development of certain phases of the subject.

PURER IRON PRODUCED ELECTRICALLY

Pig iron is now the basic form from which all types of iron and steel are made but it may become obsolete and the direct manufacture of malleable iron and steel from ore may follow the invention of a special electric furnace of commercial size that has been built in the great Hagfors, Stockholm, Sweden, ironworks where iron ore and coal mixed and fused have been made to produce pure iron containing only two per cent of carbon, and steel that can be worked in the usual manner.

The new process is continuous and fusion ceases only temporarily when the furnace is tapped, while the absence of gases and slag produces a superior product.

The United States leads the world in the number of electric steel furnaces in use, and with the discovery of a process of making iron and steel directly from ore would give a tremendous impetus to the use of the electrical smelting furnace.

Studies of Transmission Stability

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Associate, A. I. E. E.

and

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Synopsis.—*Stability may be defined as the capacity of a power system to remain in equilibrium under steady load conditions, and its ability to regain a state of equilibrium after a disturbance has taken place. The lack of stability first manifested itself in the cases of overloaded machines and high impedance tie lines. The transmission of large blocks of power over long distances has presented the problem in a new form. Attention was directed to this problem in a group of papers before the Institute at the Midwinter Convention of 1924.*

These papers gave a general discussion of the stability problem and pointed out the necessity of considering the limitations imposed not only by the line alone but by the transformers, rotating machines and load. Extensive and pertinent discussions followed which emphasized the importance of the limitations imposed on power transmission by stability conditions.

The papers and discussions at the 1924 Midwinter Convention established a method for the determination of power limits under steady load conditions assuming fixed excitation. The limit so determined is due to the inherent characteristics of machines and does not take into account the possibility of changes in excitation due to the action of voltage regulators. The possibility of exceeding the "inherent stability limits" by the operation of the voltage regulators and exciters was pointed out. This condition of "artificial stability" was not at that time believed to be attainable. It was recognized that under the actual operating conditions on a transmission system instability would occur because of short circuits or other disturbances at a point considerably below the maximum static limit.

Subsequently extensive studies of stability conditions were made to determine the feasibility and economics of a number of large transmission projects. These studies emphasized the necessity of determining the maximum permissible load under the most severe operating conditions which obviously arise at the time of system disturbances, such as switching operations or flashovers with the attendant switching.

Transmission stability has been the subject of a number of articles in the technical press and of papers before the Institute, the principal ones of which are listed in the bibliography. C. L. Fortescue's paper before the Seattle Convention in September 1925 serves as an introduction to the present paper, presenting in a qualitative manner results of recent investigations whereas this paper presents methods for the quantitative determination of system oscillations.

During the early part of 1925 extensive stability tests including switching operations and single phase faults to ground were conducted on the system of the Pacific Gas and Electric Company. These tests will be described in a companion paper by Roy Wilkins.†

The present paper first deals with the principal elements entering into the stability problem, such as the action of generators and exciters during disturbances, effect of dissymmetry produced by single-phase short circuits, simplification of the load end network and methods for combining these various factors in the determination of the electromechanical oscillations of the system following major disturbances. Results of calculations by these methods are compared with the results of tests on the system of the Pacific Gas and Electric Company. The paper concludes with a discussion of various methods of improving stability.

Introduction

FUTURE power developments in this country and in Canada will involve the transmission of larger blocks of power over greater distances than hitherto have been realized in actual practise. Attention is being directed to the possibilities of hydroelectric developments located remote from load centers. In order to compete on an economical basis with high efficiency steam plants located near load centers, it is necessary to transmit large amounts of power per circuit. However, electrical considerations show that the power limits per line closely approach the limits determined by economical considerations. For these reasons the stability of transmission systems is particularly important.

The present investigation of the stability problem has for its object the determination of power limits for a transmission system under the various conditions that arise in actual operation. The results which may be expected of such an investigation include (1) the determination of the proper basis of design of machines and control apparatus for future power developments involving long transmission lines, (2) the development of methods of analysis and testing equipment to determine the performance of existing systems, (3) the improvement of operating methods with a view of reducing the effects of disturbances. This should follow naturally as a result of the better understanding of what takes place during and following a disturbance.

Stability may be defined as the capacity of a power system to remain in equilibrium under steady load conditions and its ability to regain a state of equilibrium after a disturbance has taken place. The first part of this definition is referred to as "static stability" and the second part as "transient stability." It should be noted that after a disturbance the system will not necessarily seek the original state of equilibrium.

The maintenance of stability on a transmission system is obviously of the utmost importance since a line deficient in stability is inoperative. Normal loads on a system must, of course, lie well below the static limit. The importance of transient limits depends largely upon the importance attached to the interruption in power supply over the transmission line. If switching out of a section of line for inspection or repair at times of heavy load would always lead to loss of synchronism, the operating conditions would be intolerable. If the increases in load, which normally take place on a sys-

*Both of the Westinghouse Electric & Mfg. Company.

†"Practical Aspects of System Stability" JOURNAL of A. I. E. E. Feb. 1926.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, Feb. 8-11, 1926. Complete copies available upon request.

tem, would result in loss of synchronism, the operating conditions would also be intolerable. If any kind of a fault on a transmission system would always lead to loss of synchronism, the operating conditions would be unsatisfactory. It is recognized that stability cannot be maintained under all abnormal conditions, but the layout should be such as to prevent loss of stability under the more frequently occurring conditions, such as the addition of a reasonable block of load, normal switching operations, and the majority of single-phase, line-to-ground faults. The decision as to the standard of service is important, and, in our opinion, nothing less than that suggested above will be tolerable for the super power transmission systems which have been contemplated.

Reference should be made to the paper by C. L. Fortescue, presented at the Seattle Convention in 1925, which gives a general discussion of static stability and presents a picture of the phenomena taking place during transients. Mr. Fortescue's paper serves as an introduction to the present paper, the former presenting in a qualitative manner results of recent investigations whereas the latter presents methods for the quantitative determination of system oscillations.

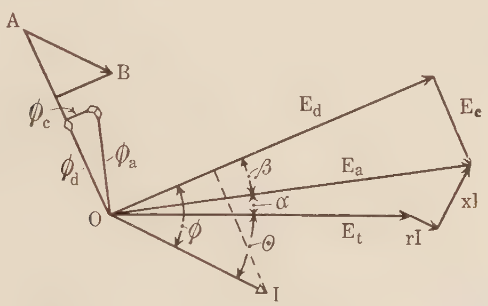

FIG. 1—GENERATOR VECTOR DIAGRAM

METHOD OF CALCULATION OF SYSTEM DISTURBANCES

System disturbances set up oscillations which are essentially the same phenomena regardless of the method of initiation. Consequently, the same general methods of calculation may be applied to of all them. The performance of a system during and following a disturbance will involve the following problems; generator and exciter characteristics, simplification of the load-end network, inertia effect of rotating machines, governor characteristics, dissymmetry due to single-phase short circuits, and methods of combination of electrical and mechanical oscillations into one final result.

GENERATOR CHARACTERISTICS

The effect of generator characteristics during transients can be analyzed conveniently by the Blondel two-reaction method in which the flux is resolved into two components, a direct component in phase with the field poles and linking the field windings and a cross component in quadrature with the field poles. Referring to Fig. 1, I is the armature current, E_t terminal voltage and E_a internal voltage. The latter voltage is resolved into two components, E_d and E_c, which are produced by rotation of the direct component and cross component of flux respectively. During transients, these components, which have associated with them different windings, have different decrements. In salient pole machines test results indicate that the cross component of flux can be assumed to vary instantly to its new value and the variation in direct component of flux can be calculated at any instant by the following formula

$$\frac{d\,E_d}{d\,t} = \frac{10^8}{n\,N\,C_1}\,(e_x - i\,r)$$

where

e_x = exciter voltage at any instant.
$i\,r$ = voltage drop in the field at any instant.
n = turns per pole of field winding.
N = number of poles.
C_1 = flux per pole per generator terminal volt.

The construction of large turbo generators is such as to produce a damping action which prevents rapid change in cross component of flux. In this case, it is sufficiently accurate to assume that the total internal voltage E_a is fixed in phase position relative to the field structure during transients, and that the total component varies in proportion to the direct component.

EXCITATION SYSTEMS

Excitation systems serve to supply the m. m. f. required in synchronous machines to produce the direct component of voltage of such value as to maintain any desired terminal voltage. With hand-operated systems, the excitation remains constant during the transient unless changed by the operator, but with automatic regulators changes in excitation normally take place. Automatic voltage regulators are of two principal types, the vibrating or Tirrill type and the rheostatic type.

The vibrating regulator functions by cutting a block of resistance "in" or "out" of the exciter field circuit at such a rate as to maintain the proper mean value of exciter voltage to supply the required field current for the main machine. The rate of change of exciter voltage for the transient conditions as the contacts open and close can be calculated by the following formula:

$$\frac{d\,e}{d\,t} = \frac{k}{N\ \ n}\,(e - i\,r)$$

where

N = number of poles.
n = number of turns per pole.
ϕ = flux per pole.
e = $k\,\phi$.
k = voltage produced by rotation of unit flux.

The quantity in parenthesis represents the difference between the terminal voltage and the $i\,r$ drop in the field winding of the exciter, and represents the voltage which must be supplied by the inductive drop in the field winding. This equation expresses the relation

between the rate of change in terminal voltage of the exciter with time as a function of e and i, and enables one by a step-by-step method to determine the exciter voltage as a function of time.

With the rheostatic type of regulator, the exciter voltage remains constant, but the resistance in the main field of the alternator is automatically varied by means of a motor-operated face plate rheostat controlled by the regulator. It may be noted that with this type of regulator the operation occurs in the field circuit of the main machine, whereas with the vibrating type, the operation occurs in the field circuit of the exciter. With the vibrating regulator there is a time lag in the building up of the voltage across the machine terminals due to the time constants of the exciter field, whereas with the rheostatic regulator, a certain amount of time is required for the movement of the motor-operated rheostat.

The Load End Network

A transmission line will usually deliver power to a load end system of considerable extent and having other sources of power. Frequently this "load end network" will have connected to it much greater capacity than the output of the transmission line. The load end network constitutes a problem in stability studies, because rigid analytical methods are frequently impractical on account of the complexity of the network, and because it is difficult to find a network that is equivalent to the actual network, at the same time being sufficiently simple to be handled analytically.

The load end network includes synchronous generators and condensers in addition to the load the principal components of which are synchronous motor, synchronous converter, induction motor and lighting load. E. J. Amberg has given the following segregation of load on a particular system, which segregation appears to be quite typical:

TABLE III

Typical Segregation of Peak Load

Type	Percentage
Induction motor	60
Synchronous motor	10
Synchronous converter	10
Lighting	—20

The various types of load have different characteristics. With synchronous and induction motors, the true power demand may be assumed to remain constant with variation in voltage, whereas the lighting and synchronous converter load will vary as the square of the voltage. The reactive power varies greatly with the type of load and in the curves of Fig. 7 are shown the variations of reactive power with variation in terminal voltage.

It is impractical to consider a multitude of individual loads, and it becomes necessary, therefore, to use some such composite load characteristic as shown in Fig. 8. An approximation of the load characteristics that is very convenient is the assumption of a constant impedance shunt load. The variations in load voltage usually are not great because it is maintained by the local generators and synchronous condensers. It is this fact which permits the relatively crude approximation of constant impedance load to give satisfactory results for the majority of cases.

The load characteristic is also affected by changes in system frequency. Quite definite information on this point is available from actual operating experience. J. P. Jollyman* has stated that a reduction in frequency from 60 to 59 cycles will reduce the real power demand by 3.5 per cent.

The method to be employed for analyzing load end networks from the standpoint of stability is dependent chiefly upon the number of synchronous machines. In case the load end network involves one synchronous machine and induction motor and lighting load the network may be replaced by a single synchronous machine with a shunt admittance branch to represent the non-synchronous load. In case there are two or more synchronous machines which would carry proportional loads at times of disturbances, they may be handled in a similar manner. In many cases, the assumption that the voltages of all load end synchronous machines are in phase represents a crude approximation. A quite accurate assumption for such a case is to assume that a constant angular relation between the various synchronous machines is maintained. By this method the synchronous machines are compelled to operate as a unit instead of permitting them to make small movements with respect to each other. On very large receiving systems, disturbances on the transmission system are likely to have relatively little effect on individual machines and it becomes permissible to represent an extensive transmission network with many sources of voltage by a single equivalent network with a single machine and a single shunt admittance to represent non-synchronous load. For very large receiving networks the inertia may be considered infi-

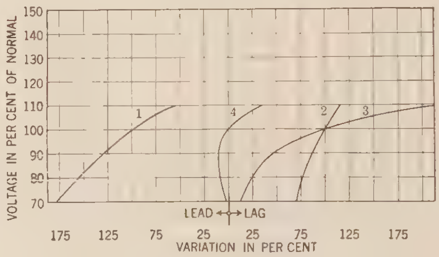

Fig. 7—Variation of Reactive Kv-a. with Voltage

1. Synchronous motor—75 per cent load, 85 per cent p. f. lead (at normal voltage)
2. Induction motor, 75 per cent load, 79 per cent p. f. lag (average at normal voltage)
3. Transformer exciting kv-a.
4. Synchronous converter (reactive kv-a. in per cent of machine rating)

*Stored Mechanical Energy in Transmission Systems, A. I. E. E. Journal, Sept. 1925.

nite or if desired corrections may be introduced in the inertia of the supply end generator.

Mechanical System Data. The stored mechanical energy in the synchronous rotating machinery is important in determining the period of system oscillations and the rate of change of angular positions of rotors, and hence internal voltage in response to changes in input or output. Because of their inertia, the rotors cannot change phase position immediately. During the first instant of a disturbance the redistribution of power can be calculated with the internal voltages in the same position as at the instant immediately preceding a disturbance. Before the beginning of the transient the input and output are equal, the rotor being in equilibrium, but with the redistribution of power the equilibrium is disturbed and the rotors accelerate or decelerate, the rate being determined by the following equation:

$$a = \frac{180\,f}{E}\,\Delta P \qquad (6)$$

where

α = acceleration in electrical degrees per sec. per sec.

f = system frequency.

E = stored mechanical energy at synchronous speed in kilowatt seconds.

ΔP = difference between input and output in kw.

By assuming sufficiently small time intervals and assuming the acceleration constant during the interval, or by assuming larger intervals and correcting for average acceleration, the rotor movements can be traced by a step-by-step method of calculation throughout the period of disturbance.

The stored energy is dependent upon the total mass, the distribution of this mass, and speed. The following table indicates the stored energy in kilowatt-seconds per kilowatt output for a large number of different units of each type of machine.

TABLE IV

STORED ENERGY OF MACHINES

1. *Water Wheel Generators.* Average of units ranging from 1500 to 35,000 kw. = 2.40 kw.-sec. per kw. From an examination of a small amount of data the flywheel effects of the waterwheels appear to be in the neighborhood of 10 per cent to 20 per cent of the generator flywheel effects.

2. *Steam Turbine Generator Units.* Average of units ranging from 1500 to 35,000 kw. Generators = 5.32, turbines = 5.65. Total = 10.97 kw.-sec. per kw.

3. *Rotary Converters (Railway & Edison).* Average of units ranging from 750 to 3250 kw. = 2.10 kw.-sec. per kw.

4. *Synchronous Condensers.* Average of units ranging from 1000 to 40,000 kv-a. = 1.48 kw.-sec. per kv-a.

The synchronous machinery, and to a lesser extent, the eddies in synchronous machinery, tend to cushion any sudden changes in phase position and voltage. This induction generator effect differs from the synchronous effect in that it is responsive to speed changes rather than angular space changes. However, the effect is small and may be neglected.

Governor Characteristics

The time constants of governors are also important in their effect upon system stability during certain types of disturbances. The acceleration or deceleration of the rotor determining the phase position of the internal voltage depends upon the difference between generator input and output, the input being regulated by the governor. In present day practise, the governor is a device which functions on speed. This point is important as large angular displacements might take place before the governing device begins to function.

In general, however, since governors react only after the speed change and since these changes are extremely small during switching operations, the variations in gate opening can be neglected for these conditions. The action of the governor during single-phase short circuits will depend upon the change in output and the resulting speed change occasioned thereby. For relatively small changes of the order of 25 per cent of rated load, consideration of the "dead time" and the relatively slow traversing rate of about six seconds would justify neglecting any change in gate position due to governor action. In general, one must look into the individual case and determine whether or not the effect of governors can be neglected. If their effect must be taken into account, it will be found convenient in the analysis to plot the variation in speed of machines and in gate opening as functions of time. These curves enable one to determine the interaction between rotor velocity and gate opening throughout the transient condition.

Single-Phase Short Circuits

The calculation of single-phase, short-circuit currents on a transmission network is complicated, because the currents and voltages in the different phases are unsymmetrical. Each phase is inductively coupled with the other phases in transmission lines, transformers and rotating machines. In addition, rotating machines, including synchronous generators, motors and condensers, and also induction motors, provide a distinct phase-balancing action, tending to restore symmetry in voltage and current. Because of the fact that no suitable method had previously been published, the authors found it necessary to develop a method for the solution of the single-phase, short-circuit problem. This method is essentially a combination of two well-known methods of network solutions; namely, phase sequence components, and general circuit constants. In the phase sequence method developed by C. L. Fortescue,* the voltages and currents of a three-phase grounded system are resolved into three components, namely, the positive sequence, the negative sequence, and the zero sequence. This results in an important simplification for the case we are considering of balanced polyphase systems, as the different sequences do not react one upon another. For normal balanced loads, only positive sequence voltages and currents are

*Trans. A. I. E. E., Vol. XXXVII, p. 1027.

present. In case of a line-to-line fault, only the positive and negative sequence components are present; while in the case of a fault to ground, all three components are present. Synchronous machines generate only positive sequence e. m. fs. and the negative and zero sequence voltages appearing at machine terminals are due to the voltage drops produced by negative and zero sequence currents, respectively. Since polyphase synchronous machines generate only positive sequence voltages, it follows that machine decrements involve only positive sequence voltages and currents, and the constants of the machines and the network to which they are connected. In other words, it is possible to compute the decrements for single-phase short circuit by the methods applicable to three-phase short-circuits if the positive sequence voltages and currents of the various machines are considered.

The most convenient methods for handling transmission networks employ the general circuit constants developed by Evans and Sels. In this connection, it may be pointed out that the recent revision of the book "Electrical Characteristics of Transmission Lines" by William Nesbit gives a very complete series of tables of the general circuit constants for transmission lines covering the commercial ranges of conductors and spacings for lines from 50 to 300 miles in length. The method of general circuit constants was originally developed for the solution of balanced three-phase systems where only positive sequence components of currents and voltages are present. The method, however, can readily be extended for negative and zero sequence components.

It can be shown that the effect upon the positive sequence voltage and current of a wire-to-wire or wire-to-ground fault can be accurately represented by replacing the fault by a symmetrical impedance to ground. For a line-to-ground fault this impedance per phase will be equivalent to the sum of the negative and zero sequence impedances as measured at the point of fault, and for the wire-to-wire fault the equivalent impedance is equal to the negative sequence impedance as measured at the point of fault.

Combination of Factors

The various individual factors entering into the problem of stability have been discussed in the previous section. These factors are combined in a step-by-step method to obtain the magnitude of system oscillations. Reference should be made to the complete paper for a more detailed description of the method. The results of the calculations are plotted in the form of angle time, voltage time, and power time diagrams from which a very good estimate of the stability of operation can be obtained.

Application of Methods to Various Types of System Disturbances

The methods of calculating system oscillations described in the preceding Section will now be discussed with respect to their application to the various types of system disturbances. The principal conditions which may give rise to important disturbances on a power system are as follows:

1. Sudden increases in load.
2. Switching operations.
3. Faults.

For a general discussion of the phenomena accompanying these various types of disturbances, reference should be made to the paper by Mr. Fortescue.

Sudden Increases in Load

The supply of power from long-distance transmission lines is usually supplemented by local steam or hydroelectric power plants. In ordinary operation, sudden increases in load do not occur except in the case of the loss of a load end generator as the result of a breaker operation. For this condition, however, the load is taken up largely by the retardation of the parallel units which initially tend to contribute power in inverse proportion to their connecting impedances. The increased demand for power will require a new position of equilibrium and before reaching it, the system on account of mechanical inertia will tend to overshoot and go out of step if the transient limit is too low. If the system withstands the first overswing, both ends of the system will usually stay in step and slow down simultaneously. The increased load will cause a reduction in system frequency and in machine voltages which will bring the governors and voltage regulators into action, tending to restore the system to normal.

Switching Operations

The switching operation most likely to be important from the standpoint of stability of a transmission system is the opening of a section of line under load. The switching out of a section of line will cause the system to seek a new position of equilibrium, and the system in moving to this new point will overswing to such an extent as to produce instability if the transient limits are too low. If the system does not pull out of step on the first overswing, it is unlikely to do so later because sufficient time will usually be available for regulators to increase the excitation of the machines.

Faults

From the standpoint of maintaining stability, faults produce most severe conditions occurring in ordinary operating experience.

Three different types of faults may occur; namely three-phase, single-phase line-to-line, and the single-phase line-to-ground. High-voltage transmission systems are normally designed with neutral grounded and with relatively large clearances between conductors. There is a distinct tendency to employ single circuit tower lines and horizontal spacing of conductors on account of ice conditions. Greater attention is being given to substation layout in order to minimize the possibility of three-phase and single-phase line-to-line

faults. These considerations indicate that the occurrence of any type of fault other than the single-phase line-to-ground is relatively remote. Data on some of the high-voltage transmission circuits indicate that over 90 per cent of the faults that have occurred were from line to ground. In view of these facts, it appears that the layout should be such as to provide a reasonable margin of stability in the case of single-phase line-to-ground faults, but that it is not essential in the case of three-phase and single-phase line-to-line faults.

A fault on a transmission line will normally give rise to three circuit conditions; namely, the original condition before the fault, the condition during the fault, and the condition after the fault is cleared; and in addition another intermediate step if more than one breaker is required to clear the fault. The time interval between these changes in circuit conditions is insufficient for the system to readjust itself, consequently the changes may occur at such times as to augment the magnitude of the system oscillation. The description of the way in which the opening of a breaker to clear a line-to-neutral fault may give rise to very large system oscillations, is given in the paper by Mr. Fortescue previously referred to.

Studies of faults should not be limited to the high-voltage lines alone, but should include the distribution system and also the low-voltage bus at generating stations or at substations.

Static and Artificial Stability

In previous papers on transmission stability the subject of static stability has received most consideration. The published methods for determining the static stability limits have employed the assumption of constant field current in synchronous machines. It is to be noted that the limits so calculated are dependent only upon inherent characteristics of the machines and the other parts of the system. E. B. Shand pointed out the theoretical possibility of maintaining a condition of "artificial" stability in which the inherent static limits could be exceeded by operation of regulators and exciters. It was then generally believed and at that time not contradicted that the speed of commercial regulators and exciters was insufficient to permit the attainment of artificial stability on actual power systems. Adequate methods of transient analysis were not then available, and only by means of transient analysis or tests as on a miniature system, is it possible to prove that artificial stability may be obtained on commercial systems. Artificial stability may be defined as the condition of stable operation of power systems which is attainable only through the operation of the automatic voltage regulators and exciters. The time available for the functioning of this apparatus is dependent upon the rate of change of rotor position and the time constants of machines. The natural period of mechanical oscillation of a power system under light load conditions is of the order of a second or less, but in the vicinity of the static limit the natural period becomes longer. At the static limit the time constants of machines become the controlling factors in determining rotor movements. On this account sufficient time may be available for important changes in excitation as a result of the operation of voltage regulators.

Artificial stability can best be considered as a series of periodic transients and for this reason will be investigated by the methods of transient analysis. Calculations were made to show the possibility of obtaining a condition of artificial stability on systems equipped with commercial apparatus by considering the simple case of a generator and motor connected through a reactance tie. A load in excess of the static limit at normal terminal voltage and with constant excitation was assumed. The angle between rotors was arbitrarily increased by a small amount and calculations were made of the resulting oscillation taking into account the transients in machine fluxes and the effects of

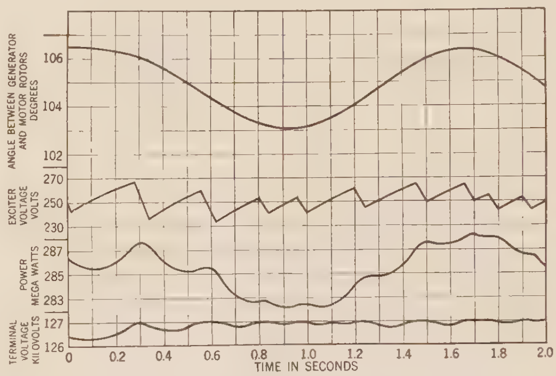

Fig. 13—The Effect of the Excitation System in Maintaining Artificial Stability

exciters and regulators and also the mechanical movements of rotors. The results of the calculations are given in Fig. 13 which indicates the possibility of securing artificial stability by the use of commercial regulators and exciters. The significant thing to note is the fact that the mechanical oscillation was so slow that the voltage regulator had time to open and close several times during an oscillation.

Analysis of Stability Tests

Cooperative stability tests were made during the early part of 1925 on the transmission system of the Pacific Gas & Electric Company as described in a companion paper by Mr. Roy Wilkins. Such tests furnish accurate information as to the operation of a system at times of disturbances and are valuable for planning future expansion. In addition, these tests which were the first of their kind, afford an opportunity to check methods of calculations and to analyze test results on an actual transmission system.

These tests are described in detail in the companion paper by Mr. Wilkins. The present discussion will be restricted to the comparison of test results and calcula-

tions. Two representative tests, one a switching operation and the other a single-phase fault, were selected for analysis.

Switching Operation

The layout of the part of the Pacific Gas & Electric Co. system involved in these tests is indicated in Fig. 14. One transmission line was operated at "110 kv." and the other at 220 kv. In test No. 12, the one selected for analysis, a switching operation was performed by opening the high voltage breaker in the 220-kv. line at the Pit River No. 1 powerhouse, transferring all of the load to the 110-kv. line. A relatively severe switching disturbance is produced in this manner as the load on the 110 kv. line is increased to over 300 per cent of the initial value.

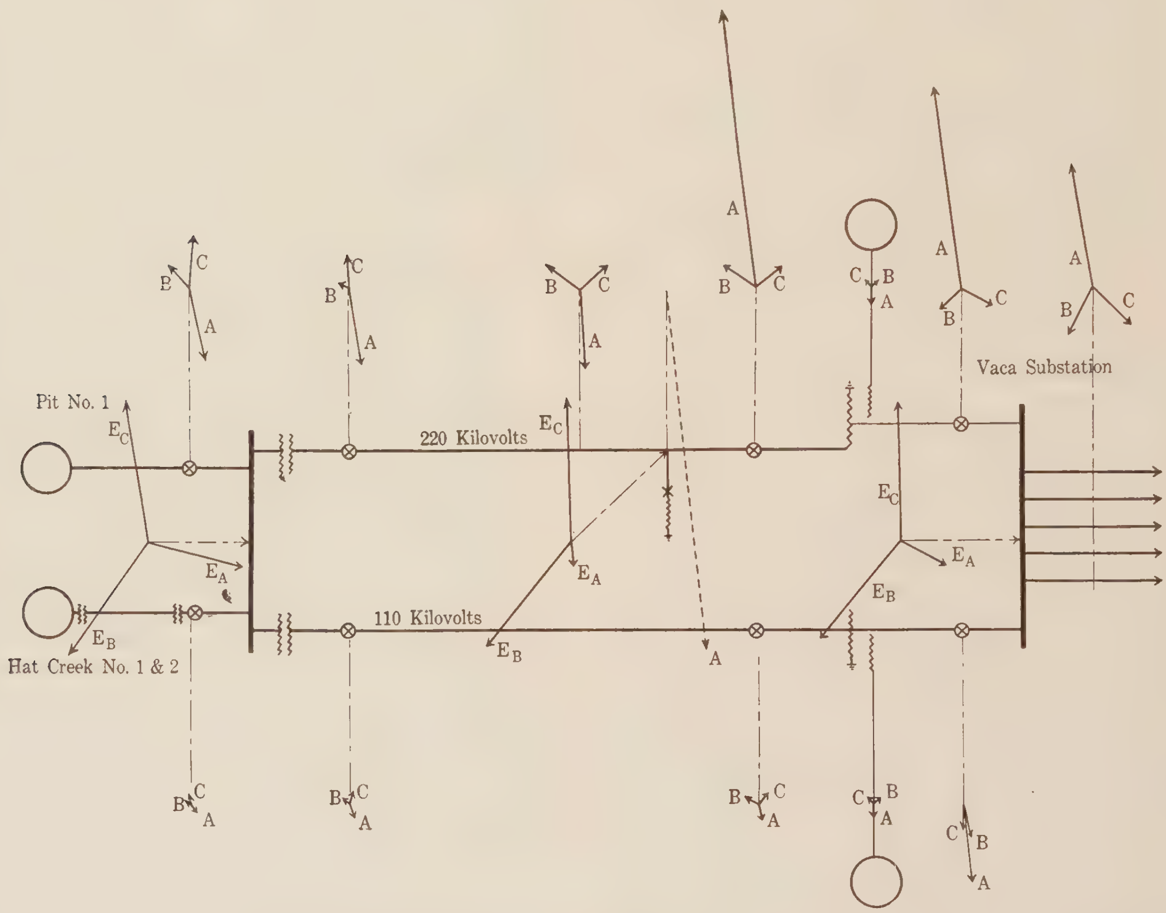

FIG. 14—VOLTAGE AND CURRENT DISTRIBUTION ON TRANSMISSION SYSTEM OF PACIFIC GAS & ELECTRIC COMPANY

With a single-phase fault to ground on 220-kv. line near Vaca substation—calculated. Voltage 30,000 volts per in.; current, 500 amperes per in., 110-kv. base

The application of the methods of calculation previously described to the particular problem will now be discussed. The load end network consists of the 110-kv. and lower voltage distribution system, connected loads and local generators and the synchronous condensers at the Vaca-Dixon substation. This type of network may be considered as involving two sources of e. m. f. having a fixed angular relation, and a shunt impedance load and may be analyzed by the use of one of the equivalent "load end networks." The supply end network involves three power plants in parallel, Pit River No. 1, Hat Creek No. 1 and No. 2. Since Hat Creek No. 1 and No. 2 are very close together and their electrical and mechanical characteristics are similar they can be considered as one unit but due to the difference in impedance and inertia effects the Hat Creek plants cannot be combined in this manner with the Pit River No. 1 plant. This necessitates a set-up consisting of two salient pole machines at the supply end and a single equivalent machine at the load end with a shunt impedance branch representing non-synchronous load. The solution is then obtained by the step-by-step method, assuming constant gate opening for the supply end, constant direct component of voltage at the supply end generator, and constant internal voltage at the load end machines.

Results of the calculations of the switching operation are shown by a number of curves of power, voltage and angle plotted as functions of time from the beginning of the disturbance. In the curves of Fig. 15 are shown the calculated and observed values of power measured at Pit River No. 1. Similar curves for the generator voltage at Pit River No. 1 and the 110-kv. bus voltage at Vaca are given in Fig. 16. Fig. 17 shows the in-

stantaneous observed and calculated angles between the rotor of the Pit generator and the voltage of the 110-kv. bus at Vaca.

It will be noted that the curves show good agreement between calculated and observed values as to general magnitude and trend. It should be explained at this time that the breaker did not open the circuit completely at the beginning of the switching disturbance. This accounts for the time displacement of about 0.2 seconds in the observed results and also for the fact that the observed oscillation is of somewhat smaller magnitude.

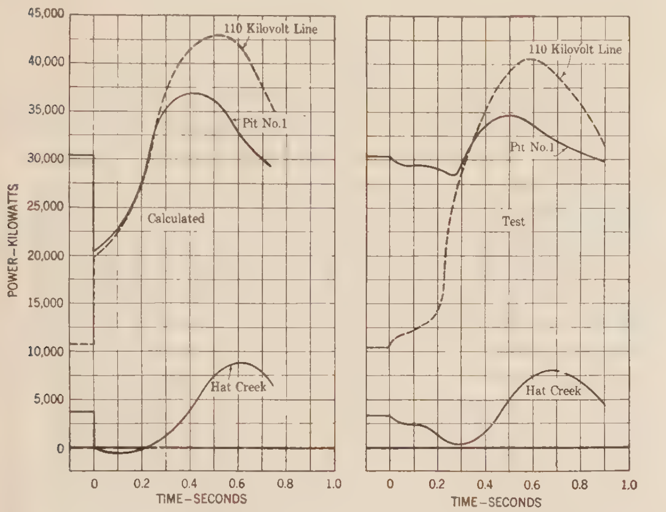

FIG. 15—COMPARISON OF TESTS AND CALCULATIONS OF POWER-OPENING ONE LINE

SINGLE-PHASE FAULT TO GROUND

The system layout for the single-phase fault to ground was the same as for the switching test previously described. The fault was applied to the 220-kv. line two towers from the Vaca-Dixon substation.

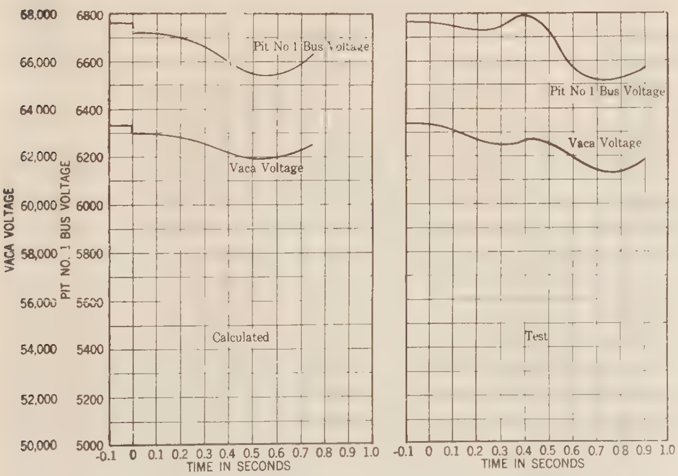

FIG. 16—COMPARISON OF TESTS AND CALCULATIONS FOR VARIATIONS IN VOLTAGE OF PIT NO. 1 BUS AND VACA 110-KV. BUS-OPENING ONE LINE

An analysis was made to determine the initial distribution of currents and voltages over the entire system by the methods outlined in Appendix II. The simplified network identical to that used for the calculations of switching operation was used with the "equivalent symmetrical network" connected at the point of short circuit. The conditions of tests were unusual in that the closely coupled transmission lines were operating at different voltages.

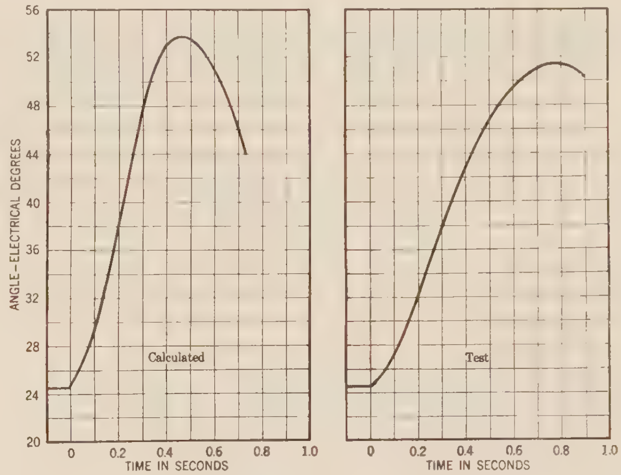

FIG. 17—COMPARISON OF TESTS AND CALCULATIONS OF ANGLE BETWEEN VACA BUS VOLTAGE AND ROTOR OF PIT NO. 1 GENERATOR,—OPENING ONE LINE

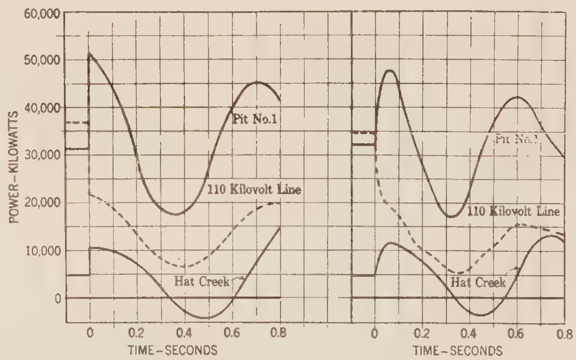

FIG. 18—COMPARISON OF TESTS AND CALCULATIONS OF POWER—CLOSING ONE LINE

Tests were also made and the transients recorded when the same breaker was closed. The results of tests and calculations of power variations for this condition are shown in Fig. 18. In this case the effect of the non-simultaneous action of the different poles does not enter and a very close check is obtained.

TABLE V

COMPARISON OF MEASURED AND CALCULATED INSTANTANEOUS SYMMETRICAL VOLTAGES AND CURRENTS FOR FAULT TO GROUND AT VACA-DIXON SUBSTATION

	Measured	Calculated
1. Residual current in circuit breaker at Vaca	1020	1130
2. Voltage, A phase at Vaca	60000	59300
3. Residual voltage, 110-kv. bus at Vaca	14200	13300
4. Residual current in 220-kv. line at Pit. No. 1	140	138
5. Current, B phase, 220-kv. line at Pit No. 1	235	280
6. Current, A phase, Pit No. 1 generator*	2780	4150
7. Voltage, A phase, Pit No. 1 generator	4840	4996
8. Current A phase, 110-kv. line low side at Pit No. 1	1070	1030

*Discrepancy unexplained.

The results of calculations are shown in Fig. 14 which gives the vector distribution of the currents and voltages at different points in the system. In this figure, all the vectors are given on a common voltage basis of 110 kv., and to obtain the actual values of current and voltages in any particular part of the circuit it is necessary to take into consideration the transformer ratios and phase shifts due to the star-delta transformations. The diagram assumes the normal direction of power flow from the Pit end toward the load. The fault actually occurred on Phase *B* but, for convenience in calculation, it was assumed to occur on Phase *A*. It will be noted that at the time of fault the negative phase sequence current supplied from the condensers at Vaca are greater than the positive sequence components. The pronounced distortion of the current vectors is due largely to the low value of the transmitted load at the time of the tests.

In Table V is given the comparison of calculated voltages and currents with the corresponding quantities observed during the tests. The calculated values are based on the instantaneous symmetrical value of short circuit current and the test results are based on the values during the fourth cycle after the application of the fault. The close agreement considering the factors involved serves as a sufficient check upon the general method.

Methods of Increasing Stability

The most evident method of increasing the stability limit of a transmission system for a given voltage is to decrease the series impedance. This may be accomplished by the use of:

1. Additional circuits.
2. Lower frequency.
3. Percy Thomas split conductor.
4. Lower transformer impedance.

Another important general method for increasing the power stability of a transmission system is to employ measures to maintain or increase terminal voltages. This may be accomplished by the use of the following methods:

1. Machines of special characteristics.
2. Compensated machines.
3. High speed excitation.
4. Intermediate condenser stations.
5. Shunt reactors.
6. Additional tie lines at the receiver end of the system.

The layout of a transmission system may be modified so as to limit the magnitude of short-circuit currents. This can be accomplished by the use of reactors or transformers, and the avoidance of the bussing arrangements ordinarily employed. This method is open to the objection that it is not sufficiently flexible to meet the requirements of changing operating conditions.

Preliminary investigations of governor characteristics also indicate that certain modifications would be quite effective in maintaining system stability.

These general methods for increasing stability together with a certain amount of supporting test data are discussed in more detail in the unabridged paper.

The authors wish to take this opportunity to express their appreciation of the cooperation and assistance of the engineers of the Pacific Gas & Electric Company—especially Messrs. J. P. Jollyman and Roy Wilkins—in affording opportunity of investigating stability conditions on a large, high-voltage power system. In addition, they also wish to acknowledge the assistance of their associates, particularly Mr. S. B. Griscom, who has made important contributions to the methods presented.

Conclusions

Stability is an important limitation in the transmission of large amounts of power per circuit over long distances. Provision for securing stability should be made for both steady state and the more frequently occurring abnormal conditions. The limiting condition, as indicated by these studies, is the single-phase fault to ground, followed by the disconnection of the faulty section of line. Normal switching operations, except in a few special cases, will not give rise to severe system disturbances. Under emergency conditions in which a large proportion of the lines are out of service, the system may approach the limit of static stability.

The static limit of systems operating without voltage regulators is determined by the inherent characteristics of the machines and lines. With voltage regulators, a condition of artificial stability may be obtained on commercial systems and the machines tend to operate on a constant voltage rather than a constant excitation characteristic.

Methods have been presented for the analysis of stability for the various conditions that arise in system operation. The principal new features are the treatment of machine characteristics, the simplification of load end networks, and the handling of single-phase faults.

Increase in the power or stability limits may be obtained by the use of a number of methods discussed in the paper. Of particular importance are high-speed excitation and machines of special design capable of delivering a relatively large increase in lagging kv-a. with drop in voltage. Mention should also be made of special governor control.

The underlying requirement for securing stability of a system delivering a large amount of power, is one of obtaining good regulation of line and terminal equipment. Improved stability conditions may be obtained by methods providing good regulation, either inherently as by compensated machines, or automatically by high-speed excitation systems.

The use of intermediate condenser stations permits the transmission of the largest amount of power per circuit. The effectiveness of this scheme may be con-

siderably increased by the use of specially designed condensers or compensated condensers, or by high-speed excitation.

Stability is important not only for high-voltage long-distance transmission, but also for low-voltages and interconnections where relatively large amounts of power are handled per circuit.

The method of operating a power system, including setting of relays and circuit breakers, sequence of switching operations, governor adjustments, etc., has an important bearing on stability. An analysis of these factors as they affect stability should lead to the selection of the operating method which would minimize system disturbances.

Heaviside's Proof of His Expansion Theorem

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Synopsis.—*Heaviside's proof of his celebrated Expansion Theorem, found scattered in his "Electrical Papers," is reconstructed. It is based upon his so-called "conjugate theorem," also discovered independently by Routh, which establishes a relation between any two normal modes of oscillation of a dynamical system. Heaviside's argument applies to systems having finite number of degrees of freedom and no repeated or null roots of the determinantal equation of the system. The relation between Heaviside's, Carson's and Wagner's proofs is also pointed out.*

* * * * *

LET an arbitrary electric network be given and suppose a unit constant voltage is impressed at a certain instant. Then the determination of the d-c. transient and of the steady state which follows consists in finding an integral of a linear differential equation of the nth order, with constant coefficients and satisfying n initial conditions. By ordinary methods the determination of the arbitrary integration constants using the initial conditions is, as a rule, extremely laborious, except perhaps in the simplest type of circuits; therefore, a formula giving directly the transient current, without requiring the determination of integration constants, would mean a considerable advance in circuit theory. If further it is realized that when the d-c. transient and the corresponding steady state are both known, the behavior of the network under all common types of impressed voltages is also known[2], the importance of such a formula becomes at once evident.

In his celebrated Expansion Theorem, Oliver Heaviside gave just such a formula. In accordance with his somewhat eccentric habits of thought, he merely wrote down his final result on page 127 of the second volume of his "Electromagnetic Theory," without giving a proof, even without the slightest hint to his previous investigations leading to this result. This seems to have eventually given rise to the impression that Heaviside did not prove his Expansion Theorem, but rather found it in some obscure fashion, peculiar to him, by considerations which might not be of the nature of a logical proof. Thus J. R. Carson in his latest paper on circuit theory[3] writes that "the Expansion Theorem was stated by Heaviside without proof; how he arrived at it will probably always remain a matter of conjecture," while K. W. Wagner[4] writes, "Heaviside gibt die Formel ohne Beweis, ja selbst, ohne einen solchen anzudeuten" (Heaviside gives the formula without proof; what is more, without giving an indication of one) and exactly the same view is expressed in a recent paper by L. Casper[5]. Now, although no proof of the Expansion Theorem, and even no indication of such, is given in the "Electromagnetic Theory," numerous scattered investigations which might lead up to this remarkable formula are found in Heaviside's "Electrical Papers" and also in many of his published writings; therefore, the possibility that he might have given a proof of his Expansion Theorem was recognized by some writers, among them V. Bush[6], L. F. Woodruff[7] and the present author[8]. It was not until quite recently, however, that a reconstruction of Heaviside's own proof of his Expansion Theorem was possible.

The first to examine Heaviside's investigations leading to the Expansion Theorem and recognize their interest, extreme generality and correctness, was T. J. Bromwich[9], who, in an exhaustive paper published in 1916, but read in 1914, not only gave an independent

1. Massachusetts Institute of Technology, Cambridge, Mass.

2. J. R. Carson, *Theory of the Transient Oscillation of Electrical Networks, etc.* TRANSACTIONS A. I. E. E., p. 346, 1919.

3. "Electric Circuit Theory and Operational Calculus." *Bell System Technical Journal*, Vol. IV, p. 685, Oct. 1925; See p. 713.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

4. "Über eine Formel von Heaviside zur Berechnung von Einschaltvorgänge," *Archiv für Elektrotechnik*, Vol. 4, p. 159, 1916.

5. "Zur Formel von Heaviside für Einschaltvorgänge," *Archiv für Elektrotechnik*, Vol. 15, p. 95, 1925.

6. "Heaviside's Operational Calculus," Mimeographed notes for use of students at Massachusetts Institute of Technology, p. 37, July, 1925.

7. "Principles of Electric Power Transmission and Distribution," p. 237, footnote, Wiley, New York, 1925.

8. "Notes on Heaviside's Operational Method," Mimeographed notes for use of students at Massachusetts Institute of Technology, p. 17, March, 1923.

9. "Normal Coordinates in Dynamical Systems," *Proceedings of the London Mathematical Society*, Vol. 15, p. 401, 1916. See pp. 415-420.

derivation of the Expansion Theorem, similar to Wagner's[10], but also showed with extreme clearness the connection between Heaviside's argument and those methods of derivation which, like Bromwich's and Wagner's make use of contour integrals to solve the dynamical equations.

Heaviside's derivation of his Expansion Theorem is based on the so-called "conjugate theorem" which we now proceed to establish. The conjugate theorem was probably first discovered by Routh[11], but Heaviside was undoubtedly unaware of Routh's results, his methods are completely independent and, further, his results are easier to state than those of Routh.

Consider an electric network of n degrees of freedom (n currents required to specify the circuit completely at any one instant). It is well known that such a network is the exact analogue of a dynamical system of n degrees of freedom in which the forces of reaction are proportional to the displacements from equilibrium or zero configuration (*i. e.*, elastic forces of Hooke type) and the forces of resistance are proportional to the velocities. In this electromechanical analogy, inductance is equivalent to coefficient of inertia, the reciprocal of capacity to the elastic coefficient and resistance to the coefficient of dissipation or frictional coefficient; electromotive force corresponds to applied force, current to velocity and charge to displacement. This fact has been already utilized in the analysis of circuit problems by mechanical models and conversely by Doherty and many others.

The equations of motion of a dynamical system of the type specified above are well known to be[12]:

$$\left.\begin{aligned}
&\left(C_{11}\frac{d^2}{d\,t^2}+B_{11}\frac{d}{d\,t}+A_{11}\right)x_1+\ldots\\
&\quad+\left(C_{1n}\frac{d^2}{d\,t^2}+B_{1n}\frac{d}{d\,t}+A_{1n}\right)x_n=F_1\\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\
&\left(C_{n1}\frac{d^2}{d\,t^2}+B_{n1}\frac{d}{d\,t}+A_{n1}\right)X_1+\ldots\\
&\quad+\left(C_{nn}\frac{d^2}{d\,t^2}+B_{nn}\frac{d}{d\,t}+A_{nn}\right)x_n=F_n
\end{aligned}\right\}\qquad(1)$$

In this system of linear differential equations, C_{KK}, B_{KK} and A_{KK} are the coefficients of inertia, dissipation and elasticity of the kth branch, x_K the displacement of the kth branch and C_{Kj}, B_{Kj}, A_{Kj} the coefficients of inertia, dissipation and elasticity between the kth and the jth branches. $F_1, F_2 \ldots . F_n$ are the external forces acting on the corresponding branches.

Equations (**1**) form the starting point of Heaviside's argument[13]. On account of the precise analogy between the electric network and the mechanical system, it is immaterial whether use is made of electrical or mechanical entities and it is permissible to change from the network to the mechanical system if only the right equivalents are used. Let Q be the rate at which energy is dissipated in the system, due to the presence of frictional forces in it, U the potential energy of the elastic forces and T the kinetic energy. The power transferred to the system by the applied forces is $\sum_{k=1}^{n} F_K\,\dot{x}_K$ ($\dot{x}_K = d\,x_K/d\,t$), so the conservation of energy gives,

$$\sum_{k=1}^{n} F_K\,\dot{x}_K = Q + \dot{U} + \dot{T} \qquad (2)$$

which says that the power delivered by the applied forces is equal to the energy dissipated, plus the rate of increase of the kinetic energy of the system, plus the rate of increase of the stored elastic energy. Q, U and T are defined in terms of the variables $x_1 \ldots . x_n$ which determine the state of the system at a given instant by the expressions,

$$\left.\begin{aligned}
2\,T &= \sum_{i,j=1}^{n} C_{ij}\,\dot{x}_i\,\dot{x}_j \qquad (C_{ij}=C_{ji})\\
Q &= \sum_{i,j=1}^{n} B_{ij}\,\dot{x}_i\,\dot{x}_j \qquad (B_{ij}=B_{ji})\\
2\,U &= \sum_{i,j=1}^{n} A_{ij}\,x_i\,x_j \qquad (A_{ij}=A_{ji})
\end{aligned}\right\}\qquad(3)$$

The symmetrical conditions imposed on the coefficients $A_{ij} = A_{ji}$, $B_{ij} = B_{ji}$, $C_{ij} = C_{ji}$ mean that there are no forces of gyrostatic origin, also no forces not derivable from a potential-energy function. Such relations are also assumed to be satisfied in the corresponding electric network, thus excluding thermionic devices, etc.

It is well known that the reduced system of differential equations obtained from equations (**1**) *i. e.*, the system obtained by putting all the impressed forces equal to zero, admits an exponential solution of the type $x_K = X_K\,e^{pt}$, X_K and p being real, imaginary or complex constants to be determined. Such solutions are called the *normal* solutions. The substitution $x_K = X_K\,e^{pt}$ transforms (**1**) from a system of linear differential equations with constant coefficients, with time as independent variable, to a system of algebraic equations with p as unknown. It is further known that the condition that the system in question have a solution is that the determinant of the coefficients shall vanish. This determinant is defined by

10. Wagner's proof of the Heaviside theorem appeared as a part of his paper already quoted (l. c. footnote 4) on March 21, 1916. Bromwich's paper was read on March 12, 1914, received April 22, 1916, published in 1916.

11. "Rigid Dynamics," Vol. 2, Articles 383, 384; 1892.

12. For a full discussion of these equations and their derivation see for example Whittaker's "Analytical Dynamics," p. 177, Cambridge, 1917.

13. "Electrical Papers," Vol. 2, p. 202. First published in his paper "On the Self-Induction of Wires," Parts 3 and 4, Philosophical Magazine, Vol. 22, pp. 332-352 and pp. 419-442, October and November, 1886; see p. 335 and p. 426.

$$D(p) = \begin{vmatrix} A_{11}+B_{11}\,p+C_{11}\,p^2 & \ldots & A_{1n}+B_{1n}\,p+C_{1n}\,p^2 \\ \cdots & \cdots & \cdots \\ A_{n1}+B_{n1}\,p+C_{n1}\,p^2 & \ldots & A_{nn}+B_{nn}\,p+C_{nn}\,p^2 \end{vmatrix} \quad (4)$$

$D(p) = 0$ is then known as the determinantal equation of the system. If p_K is a root of $D(p) = 0$, p_K also satisfies the original equations (**1**). For each root $p = p_K$ of the determinantal equation, suppose we find a solution, $l_1, l_2, l_3 \ldots l_n$ for the equations,

$$\left.\begin{aligned} &(A_{11} + B_{11}\,p_K + C_{11}\,p_K^2)\,l_1 + \ldots \\ &\quad + (A_{1n} + B_{1n}\,p_K + C_{1n}\,p_K^2)\,l_n = 0 \\ &\cdots\cdots\cdots \\ &(A_{n1} + B_{n1}\,p_K + C_{n1}\,p_K^2)\,l_1 + \ldots \\ &\quad + (A_{nn} + B_{nn}\,p_K + C_{nn}\,p_K^2) = 0 \end{aligned}\right\} \quad (5)$$

If then the initial displacements u_K and the initial velocities v_K are adjusted so that,

$$\left.\begin{aligned} \frac{u_1}{l_1} &= \frac{u_2}{l_2} = \ldots = \frac{u_n}{l_n} = A \\ \frac{v_1}{l_1} &= \frac{v_2}{l_2} = \ldots = \frac{v_n}{l_n} = A\,p_K \end{aligned}\right\} \quad (6)$$

a possible solution of the system (**1**) is given by,

$$x_1 = A\,l_1\,e^{pKt}\;x_2 = A\,l_2\,e^{pKt}\;x_n = A\,l_n\,e^{pKt} \quad (7)$$

that is, by placing,

$$X_1 = A\,l_1, \quad X_2 = A\,l_2 \quad X_n = A\,l_n \quad (8)$$

The constant A therefore fixes the amplitude of the displacement. Further, on account of the linearity of the equations, $x_r = \sum_K A\,l_K\,e^{pKt}$ is also a solution, the summation being over the roots of $D(p) = 0$. But it is by no means evident that the $2\,n$ equations (**6**), which determine the amplitude of the normal solutions, are themselves algebraically capable of solution; in fact examples can be given where the normal solutions are not algebraically independent. The most direct proof that the constants A can be found is to express them in terms of the initial values of displacements and velocities. This is done by the Heaviside-Routh conjugate theorem.

Coming back now to Heaviside's argument, suppose that all the impressed forces vanish, so that no energy can be transferred to the system, while the stored energy, due to the elastic connections of the system, is dissipated irreversibly through frictional forces. Let p_1 and p_2 be any two different roots of $D(p) = 0$, satisfying equations (**1**), so that $x_1 = X_1\,e^{p_1 t}$, $x_2 = X_2\,e^{p_2 t}$ are solutions of (**1**). Let further Q_1, U_1, T_1 be the dissipation, kinetic and potential-energy functions corresponding to the normal solution p_1 *i. e.*, to $x_1 = X_1\,e^{p_1 t}$ $\ldots\ldots x_n = X_n\,e^{p_1 t}$. Then the conservation of energy gives,

$$Q_1 + \dot{U}_1 + \dot{T}_1 = 0 \quad (9)$$

but since,

$$\dot{U}_1 = \frac{1}{2}\,p_1 \sum A_{ij}\,x_i\,x_j + \frac{1}{2}\,p_1 \sum A_{ij}\,x_i\,x_j = 2\,p_1\,U_1 \quad (10)$$

and, likewise,

$$\dot{T}_1 = 2\,p_1\,T_1 \quad (11)$$

therefore,

$$Q_1 + 2\,p_1\,(U_1 + T_1) = 0 \quad (12)$$

In the same way, let Q_2, T_2, U_2 be the dissipation, kinetic and potential-energy functions corresponding to the normal solution p_2, *i. e.*, to $x_1' = X_1\,e^{p_2 t} \ldots x_n' = X_n\,e^{p_2 t}$. We have, precisely as above,

$$Q_2 + 2\,p_2\,(U_2 + T_2) = 0 \quad (13)$$

Now, since p_1 is a root of the determinantal equation, and p_2 is also a root of the determinantal equation, therefore $x_1, x_2 \ldots x_n$ and $x_1', x_2', \ldots x_n'$ are both solutions of the original system of equations (**1**). If now, following a nomenclature suggested by Bromwich, we define the relative kinetic energy, the relative potential energy and the relative dissipation of the two normal modes of oscillation p_1, p_2, by means of the expressions

$$\left.\begin{aligned} \frac{1}{2}\,Q_{12} &= \sum_{i,j=1}^{n} B_{ij}\,\dot{x}_i\,\dot{x}_j' \\ U_{12} &= \sum_{i,j=1}^{n} A_{ij}\,x_i\,x_j' \\ T_{12} &= \sum_{i,j=1}^{n} C_{ij}\,\dot{x}_i\,\dot{x}_j' \end{aligned}\right\} \quad (14)$$

we find again from the conservation of energy that

$$\frac{1}{2}\,Q_{12}+p_2\,U_{12}+p_1\,T_{12}=0, \frac{1}{2}\,Q_{12}+p_1\,U_{12}+p_2\,T_{12}=0 \quad (15)$$

whence, by subtraction

$$(p_1 - p_2)\,(U_{12} - T_{12}) = 0 \quad (16)$$

and therefore, $U_{12} = T_{12}$, which is the so-called conjugate theorem. It says in words that the relative kinetic energy of two normal solutions (two normal modes of motion) is equal to the relative potential energy of these two normal solutions. It is to be noted quite carefully that the above reasoning holds only for the case of different roots, $p_1 \neq p_2$.

Heaviside also shows that the conjugate theorem holds for the electromagnetic system expressed by Maxwell's equations. It is to be observed in this connection that the equations (**1**) which correspond, as already explained, to the electric network, are consistent with the Maxwell circuital laws provided only that the displacement current is negligible compared to the conduction current[14], therefore any argument based on these equations applies to the dynamical system under consideration, but not conversely. The proof is quite simple, but will not be given here[15].

Now let T_{r0}, U_{r0}, be the relative kinetic energy of the normal mode corresponding to the root p_r with respect to the *initial* velocities and displacements, T_{rr}, U_{rr}, the kinetic energy of the normal mode under consideration with respect to itself. T_{r0}, U_{r0}, T_{rr}, U_{rr}, are defined by the expressions,

14. See for example M. Abraham, "Theorie der Elektrizität," Vol. 1, pp. 227-260, Leipzig, 1920.

15. Heaviside, "Electrical Papers," Vol. 2, p. 203-204.

$$\left.\begin{array}{ll} T_{r0} = \sum_{i,j=1}^{n} C_{ij}\, p_r\, l_i\, v_j & T_{rr} = \sum_{i,j=1}^{n} C_{ij}\,(p_r\, l_i)\,(p_r\, l_j) \\ U_{r0} = \sum_{i,j=1}^{n} B_{ij}\, l_i\, u_j & U_{rr} = \sum_{i,j=1}^{n} B_{ij}\, l_i\, l_j \end{array}\right\} \qquad (17)$$

whence it follows that $U_{rr} = 2\,U$, $T_{rr} = 2\,T$ (cf. equations (3)). Now if coefficients $B_K = A\, l_K$ are found as outlined above, so that,

$$\left.\begin{array}{l} U_{r0} = \sum_{k=1}^{n} B_K\, U_{K_r} \\ T_{r0} = \sum_{k=1}^{n} B_K\, T_{K_r} \end{array}\right\} \qquad (18)$$

then

$$B_r = \frac{U_{r0} - T_{r0}}{U_{rr} - T_{rr}} \text{ and } A = \frac{T_{10} - U_{10}}{T_{11} - U_{11}} \qquad (19)$$

because, by the conjugate theorem, all the differences $U_{rs} - T_{rs}$ vanish.[16]

Let us now suppose that all the applied forces save one, F_1, are zero. On account of the linearity of the equations, this is just as general as inserting forces $F_1, F_2, \ldots F_n$ in each one of the n branches. Let F be an exponential, real, imaginary or complex function of time. Then, for any x,

$$x_K = \frac{F_1}{Z\,(p)} \qquad (20)$$

$Z\,(p)$ being a function of p obtained from equations (1) by elimination of all the x's except the one desired. It is in general given by the ratio of two determinants. Now,

$$F_1 \frac{d\,x_K}{d\,p} - x_K \frac{d\,F_1}{d\,p} = -x_K^2 \frac{d}{d\,p}\frac{F_1}{x_K} = -x_K^2 \frac{d\,Z}{d\,p} \qquad (21)$$

and, by the conjugate theorem,

$$2\,(T - U) = x_K^2 \frac{d\,Z}{d\,p} \qquad (22)$$

Heaviside[17] now directs his attention to the electric network corresponding to the mechanical system so far considered and reasons in terms of voltage and current instead of force and velocity or displacement. It has been already shown that the internal connections of the system, *i. e.*, the coefficients A, B, C, determine how the variables chosen to fix the system should vary in order that the resultant system be normal and that the amplitude of the normal modes of oscillation is in turn determined by the conjugate theorem. The actual current and the actual voltage are then represented by sums of normal solutions (cf. equations (7) and (8))

$$V_K = \sum_j A_j\, u_j\, e^{p_j t} \qquad I_K = \sum_j A_j\, w_j\, e^{p_j} \qquad (23)$$

the summations being over the roots of the determinantal equation $Z\,(p) = 0$. The coefficients are, as stated, determined by the conjugate theorem.

In order to find the current due to a constant applied voltage, Heaviside makes use of the following argument: Suppose that instead of inserting a constant voltage e, a condenser of capacity C is inserted in the circuit at the same point; by allowing C to increase indefinitely the effect of a constant applied voltage is obtained. This is an essential point, as it reduces the problem on hand to a subsidence problem, with no external forces. Therefore, the current can still be obtained as a sum of normal solutions. For suppose that the condenser C is inserted in the network at a given point and at a certain instant, there being no current and no voltage in any of its branches at that instant. The problem is then to find the subsidence to equilibrium of a system under its own internal stored energy. The conjugate theorem therefore holds. Let the algebraic function expressing the relation between a voltage F_K in branch K and the current I_K in the same branch be $Z\,(p)$ (see Equation (20)); suppose now that the condenser C is inserted in the same branch K and let the corresponding function be $Z_1\,(p)$. Remove the voltage F_K, charge the condenser and switch it on branch K. We have now the subsidence problem, to be solved through the same process as before, by making use of the known properties of normal functions and the conjugate theorem.

Let w_j, u_j, be the normal mode of oscillation of current and of corresponding voltage in the branch under consideration where the condenser is inserted. Since the current is equal to the rate of decrease of charge in the condenser, therefore

$$w_j = -\,C\,\dot{u}_j = -\,C\,p_j\,u_j \qquad (24)$$

because u_j is a normal coordinate. Initially, that is, at the instant the condenser is switched on its initial voltage V is $V = \sum_j A_j\, u_j$ and $\sum A_j\, w_j = 0$, as there is no current[18]. The electric (potential) energy stored in the condenser is $\frac{1}{2}\,C\,V\,u_j$, so by the conjugate theorem

$$C\,V\,u_j = 2\,(U - T)\,A_j \qquad (25)$$

U, T being the electric and magnetic energies of the normal mode. But we have also, by the conjugate theorem

$$2\,(U - T) = -\,w_j^2 \left.\frac{d\,Z_1}{d\,p}\right|_{p\,=\,p_j} \qquad (26)$$

Therefore by (25) and (26)

$$A_j = -\frac{C\,V\,u_j}{w_j^2 \left.\dfrac{d\,Z_1}{d\,p}\right|_{p\,=\,p_j}} \qquad (27)$$

16. See Heaviside's "Electrical Papers," Vol. 1, p. 523, or "The Electrician," November 27, 1885, p. 46; also Routh, l. c. footnote (11).

17. Electrical Papers, Vol. 2, p. 372; see also his paper "On Resistance and Conductance Operators, etc," in Philosophical Magazine, Vol. 24, pp. 479-502, 1887. See p. 501.

18. The initial current is zero because A_{ij}, B_{ij}, C_{ij} are all finite.

Now substitute u_j from (24) in (27), the result is

$$w_j A_j = V \left(p_j \frac{d Z_1}{d p} \Big|_{p = p_j} \right)^{-1} \qquad (28)$$

and substituting in the second of (23):

$$I_K = \sum_j \frac{V e^{p_j t}}{p_j \, d Z_1/d p \,|_{p = p_j}} \qquad (29)$$

which is the subsidence current. Now to get the effect of a constant applied voltage, let C be increased indefinitely, keeping V constant. This is the same as though the circuit were connected to a source of infinite energy. Now the structure of $Z_1(p)$ may be readily seen to be such that

$$\lim_{C \to \infty} Z_1(p) = Z(p) \qquad (30)$$

and when C increases indefinitely one root of $Z_1(p) = 0$ approaches zero, because the condenser in the branch K introduces in the determinantal equation a term which varies inversely with C. It follows that when C increases indefinitely

$$p_j \frac{d Z_1}{d p} \Big|_{p=p_j} = p_j \frac{d Z}{d p} \Big|_{p=p_j} \quad \text{for all roots except } p = 0,$$

and for $p = 0$ (31)

$$\lim_{C \to \infty} \left(p \frac{d Z}{d p} \right)_{p=0} = Z(0) \qquad (32)$$

therefore, finally

$$I_K = \frac{V}{Z(0)} + \sum_j \frac{V e^{p_j t}}{p_j \dfrac{d Z}{d p}\Big|_{p=p_j}} \qquad (33)$$

which is the Heaviside Expansion Formula.

Two points are to be noted in connection with Heaviside's derivation. The first is that his method of reasoning applies only to the case where the determinantal equation has no null and no repeated roots, otherwise, the conjugate theorem breaks down and therefore also the expansion theorem. The second is that the proof as it stands applies only to a system with finite number of degrees of freedom.

Heaviside also gave another alternative proof of his Expansion Formula, the essential point of which is the splitting of the quotient $F_{rs}(p)/D(p)$, where $F_{rs}(p)$ is the cofactor of the element containing the coefficients A_{rs}, B_{rs}, C_{rs} in the determinant $D(p)$, into a sum of partial fractions.[19] This is also the essential point in Carson's first proof[20].

Heaviside has also tried to generalize his proof so as to apply to a system of infinite number of degrees of freedom, but his argument, while quite convincing from a physical standpoint, is not mathematical. It may be formulated analytically, but the proof of the theorem for infinite roots leads to formidable difficulties, some of which have already been examined by Bromwich[21] (l. c. footnote 9). The relation between the conjugate theorem and Wagner's method of attack has been fully treated by Bromwich and will not be taken up here.

It is almost certain that few have realized the extraordinary completeness and generality of some of Heaviside's investigations. It is in the hope of calling attention to the unexplored parts of his work, also as an effort to secure a better appreciation of his labors, that this paper has been written.

19. "Electrical Papers," Vol. 2, p. 226, where the footnote supersedes the text.

20. "On a General Expansion Theorem, etc.," *Physical Review*, Vol. 10, p. 217, 1917, also l. c. footnote (3).

21. Wagner's proof is not applicable to infinite roots as it stands, because Cauchy's residual theorem, on which his proof is based, does not apply to infinite number of poles without special investigation of the behavior of the function under the integral sign.

INSULATION IN USED MACHINES

The standards of the American Institute of Electrical Engineers and other similar rules or specifications prescribe a definite high-potential test for new electric generators and motors. Much can be said for and against subjecting insulation to a higher stress than it ever will be called upon to stand in actual operation, but at any rate the specified overpotential is a perfectly definite guide for the maker and the user of a machine. However, when it comes to a machine already in use the situation becomes quite indefinite. A used machine may be subjected to a high-potential test either as a part of periodic inspection or on special occasions—for example, after repairs to the winding or a change in connections.

Since even the best known insulation deteriorates with time, it would hardly seem rational to subject a used machine to a high-potential test of the same severity as a new machine. At the same time, when a machine is performing an important duty the operating engineer prefers to know of an impending failure in advance rather than to wait until the machine actually breaks down at an inopportune moment. To test it "destructively" is to invite such a failure, but apparently there are no reliable non-destructive physical tests to indicate the condition of insulation. Measurement of insulation resistance is not always indicative, and even a high-potential direct-current test with a kenotron may give a false assurance, since the dielectric loss is absent.

This question of dielectric tests on used machines is of considerable importance to public service companies and to users of large electric motors in various industries. With it is closely connected the problem of finding a non-destructive physical test indicative of an incipient deterioration or of the state of preservation of the insulation. The time is ripe to engage in thoroughgoing research in this direction.—*Electrical World*.

ILLUMINATION ITEMS

By the Committee on Production and Application of Light

A NEW LIGHTING ORGANIZATION IN FRANCE

A society for the improvement of illumination (Societe pour le Perfectionnement de l'Eclairage) has been organized in France by some of the leading central stations, electrical manufacturers, contractors, dealers, and others interested in the development of the electrical industry. It has its headquarters in Paris. The object of the organization is clearly set forth in a circular which, freely translated, reads as follows:

"Considerable work has been done this past year in different countries to promote the development and improvement of illumination in all fields; public lighting, industrial, commercial and residential.

"Innumerable commercial and industrial enterprises utilize electric light very poorly because no rational study has been made of the best conditions of installation. The luminous sources produce glare and harm vision, in place of lighting properly the objects or the spaces which it is intended to illuminate. It is often the same in the case of public lighting. In lighting the home, people ordinarily limit themselves to using or copying old devices without seeking to make the best of the many advantages which the use of electricity offers.

"The Society for the Improvement of Lighting (S. P. E.) proposes to collect, centralize, distribute and popularize information relative to lighting practise; to develop illuminating engineers; to conduct a campaign in favor of better lighting; to explain and to show by meetings, publications and experiments, the principles on which rational installations must be made; to study, on behalf of those who desire it, the arrangements which should be made in individual cases to obtain the maximum useful effect.

"This Society seeks no commercial profit and sells no apparatus of any kind. It places itself at the disposal of all who have need of advice or information on lighting subjects. Its advice or its information is given always gratuitously. Therefore no one need hesitate to consult it, because it has been created and organized for the purpose of popularizing better lighting."

The first six booklets which have been prepared by this organization in its campaign for better lighting present in a very forceful way, the advantages of good illumination and the need of avoiding glare. They are quite different in appearance and style than the popular advertising material here. Many lighting men in this country will follow with interest the work which the new society is doing to carry the message of good lighting to the people of France.

It is indicated that in 1925 the total amount of new financing by American public utilities, excluding steam railroads, exceeded $1,750,000,000. This figure compares with $1,500,000,000 in 1924.

LIGHTING INSTALLATIONS SHOULD BE DESIGNED FOR SUBNORMAL EYES

Intensities of illumination are generally far from adequate for perfect or "normal" eyes. To increase the intensity to the high level most suitable and economically desirable for workers with normal vision is such a formidable task that little thought has been given to that necessary for the best efficiency of workers whose vision is subnormal. Apparently it has been assumed that subnormal eyes are in an insignificant minority. However, the truth seems to be that the majority of workers' eyes are not perfect. Evidence to this effect has been accumulating of late through systematic eye examination. Furthermore, it has been found that, for seeing equally well, if possible at all with defective eyes requires a greater intensity of illumination than for normal eyes. Correcting refractive errors by means of glasses is, to some extent, equivalent to increasing the intensity of illumination; but there is enough evidence to indicate that average eyes, even if corrected by means of glasses, require more light than normal eyes to attain equal facility in seeing.

Many statistics of eye examination have been published, among the most recent being those obtained by the United States Public Health Service in two New York post offices. These are sufficient to illustrate the great prevalence of eye defects. The eyes of two thousand, five hundred employees were examined with the following results: Normal or no defects, 17.1 per cent; one refractive error or more, 73.7 per cent; one inflammatory condition or more, 14.5 per cent; one muscular unbalance or more 25.6 per cent; using glasses, 35.6 per cent. These percentages are startling, but approximately the same results have been obtained in other investigations, and a glance at the bespectacled contingent to any gathering is enough to convince one of their accuracy.

It is not surprising to those who have reached the "bifocal" stage in life that the percentage of near-sightedness and other eye defects increases as the average age of a group of workers increases. The percentage of normal eyes decreases rapidly beyond the age of forty years. In lighting practise, this means that a relatively higher intensity of illumination should be supplied in those industries where skilled labor is important, because, in general and up to a certain point, skill is acquired with age. Thus it is seen that the prevalence of defective eyes over perfect or "normal" ones makes it necessary in the practise of lighting that special consideration be accorded to them.—*Electrical World.*

The night aviator flies from Jacksonville to Miami trusting mainly to his compass save for the 70-mile stretch from Palm Beach to Miami, which is lighted. At a meeting in Fort Pierce, plans were initiated to the end that the entire 390-mile route shall become a glorious White Way.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Cleveland Has Very Successful and Well Attended Meeting

From every point of view the Regional Meeting held in Cleveland, March 18-19, was an outstanding success. An attendance of 430, intense interest in the technical papers and in the addresses by prominent men, and enjoyment of the other features distinguished this meeting. The members of the convention committee deserve the greatest praise for their efforts in planning and managing the affair.

Papers on Sectionalized Electric Drive

Sectionalized electrical drive, particularly as applied in paper mills, was the subject of the first two technical sessions which were held on Thursday, March 18, in the Hotel Cleveland, the convention headquarters. Three papers on this topic were presented and there followed a very complete discussion in which a large number of paper-mill executives and engineers took part. The discussion brought out the fact that sectional drive of paper mills is generally desirable for new mills. There were some questions as to the economic advantages of replacing mechanical drive in old mills of certain classes with electrical drive. Also there was doubt in the minds of some of the paper-mill men of the necessity for such refinements of speed regulation as those described in the papers but it was admitted that in-so-far as a better quality of paper could be produced the refinements would be justified. The three papers were: *Electrification of Paper-Making Machines*, by S. A. Staege, Westinghouse Electric & Mfg. Co.; *The Development of the Sectional Paper-Machine Drive*, by H. W. Rogers, General Electric Co., and *Sectional Paper-Machine Drive*, by R. N. Norris.

Those taking part in the discussion were: T. D. Montgomery, L. W. W. Morrow, F. C. Bowler, N. D. Paine, H. L. Sanborn, J. F. Rhodes, R. T. Kintzing, E. B. Bearce, E. B. Wright, R. S. White, C. A. Farrell, Tom Harvey, R. S. Lowry, J. H. Crossley, A. O. Spierling, H. C. Busser, W. W. Spratt, S. A. Staege, H. W. Rogers, and R. N. Norris.

Dinner, with Address by Newton G. Baker

On Thursday evening the convention dinner was held in the Hotel Cleveland. Music and a number of entertainers made this an enjoyable occasion. After the dinner A. G. Pierce, Vice-President of the Middle-Eastern District, A. I. E. E., introduced the toastmaster, C. P. Cooper, President, Ohio Bell Telephone Company, who in turn presented Mayor Marshall of Cleveland who welcomed the members in the name of the City. F. L. Hutchinson, National Secretary, A. I. E. E., responded for the Institute in a short address in which he outlined the Institute's purposes and activities. The Honorable Newton G. Baker, former Secretary of War, then gave an inspiring address on some of the major problems of American civilization. Farley Osgood, Past-President, A. I. E. E. responded for the Institute members.

Domestic Electric Refrigeration

On March 17 two addresses on electric refrigeration were given. The first of these was by C. F. Kettering, President, General Motors Research Corporation, and its title was *Some Scientific Phases of Refrigeration.* Mr. Kettering explained in a most interesting way the principles of refrigeration and their applications, as well as the requirements for producing and marketing household refrigerators. A number of interesting demonstrations helped to explain Mr. Kettering's points.

G. E. Miller, Cleveland Electric Illuminating Company, spoke on *Domestic Refrigeration from the Central-Station Point of View.* In an illustrated address he described the possibilities of the domestic refrigerator as a load builder and its value as a central-station load.

Farley Osgood, consulting engineer and Past-President of the Institute, was the last speaker on Friday afternoon. He took as his subject *Engineering and Humanity*, telling of the responsibilities and opportunities for service by the engineer in solving city, state and national problems.

On Friday at noon a luncheon was given by Vice-president Pierce to the Branch Counselors of the Middle Eastern District and a few other guests. A committee on Student Activities of the District was organized consisting of all the Branch Counselors within the District and the Vice-President and Secretary of the District. Prof. H. B. Dates of the Case School of Applied Science Branch was elected Chairman.

Visit to Nela Park

On Friday evening a trip was made to Nela Park, the laboratory and plant of the National Lamp Works of the General Electric Company. At the Park short addresses were made by R. W. Shenton of the National Lamp Works, on *Nela Park, Its Organization and Objectives*, and by Ward Harrison, National Lamp Works, on *Recent Developments in Illumination.* Following these addresses there were demonstrations of illumination for industry, automobiles and the home, and then visits were made to the laboratories and historical museums.

A number of other trips were made on Saturday morning by small groups and individuals to various places of engineering and civic interest.

The able general committee which planned this convention was as follows: A. G. Pierce, Vice-President of Middle Eastern District; A. M. MacCutcheon, General Chairman; C. S. Ripley, Secretary; L. D. Bale, Transportation; H. B. Dates, Program; C. L. Downs, Reception; H. L. Grant, Publicity; G. A. Kositzky, Finance; A. M. Lloyd, Registration; E. H. Martindale, Attendance; C. N. Rakestraw, Dinner, and I. H. Van Horn, Trips. A large number of committee members worked faithfully and effectively under these men, resulting in a most successful and enjoyable meeting to all who attended.

Regional Meeting of Great Lakes District at Madison May 6-7

A two-day Regional Meeting will be held by the Great Lakes District of the Institute in Madison, Wisconsin, on May 6 and 7, with headquarters at the Hotel Loraine. An interesting program has been arranged featuring the following topics:

Rural Electrification

Developments in High-Tension Underground Cables

Cooperative Research Relations Between the Colleges and the Industries

Performance of Radio Receiving Circuits.

On Thursday evening, May 6th, a dinner will be given at which President Glenn Frank of the University of Wisconsin will give the address.

A luncheon meeting for the Counselors of the Student Branches of the District has been scheduled for Thursday noon. Thursday afternoon will be devoted to inspection trips to points of interest such as the hydroelectric plant at Prairie du Sac, the Forest Products Laboratory, the University, the Capitol, and the industries of Madison. Several excellent golf courses will be open to members attending the meeting.

The meeting and program committee consists of the following: Chairman, Edward Bennett; J. B. Bailey, A. G. Dewars, H. R. Huntley, L. E. A. Kelso, Carl Lee and R. G. Walter.

The chairmen of the various local committees are as follows: C. M. Jansky, Publicity and Attendance; John R. Price, Hotel and Dinner; L. J. Peters, Registration and Reception; R. G. Walter, Finance; C. B. Hayden, Entertainment and Trips.

Madison is easily reached by automobile by any one of several routes. Detailed information concerning condition of roads may be obtained by addressing Mr. J. C. Bitterman, Madison Association of Commerce, Madison, Wisconsin.

PROGRAM OF MADISON MEETING

Thursday Morning

9:00 A. M. Registration.

9:45 A. M. Technical Session: R. G. Walter, Chairman.

Rural Electrification, by Grover C. Neff, Wisconsin River Power Company.

Important Features of a Successful Plan for Rural Electrification, by George G. Post, Milwaukee Electric Railway & Light Company.

These papers will be discussed by R. A. Stewart, University of Minnesota; Eugene Holcomb, Consumers Power Company; C. B. Hayden, Railroad Commission of Wisconsin; R. A. Duffee, University of Wisconsin; and E. H. Lehman, University of Illinois.

Thursday Noon, 12:30 P. M.

Luncheon meeting of Branch Counselors.

Thursday Afternoon

Inspection Trips and Golf.

Thursday Evening

Regional dinner at the Hotel Loraine. Address by President Glenn Frank, of the University of Wisconsin.

Friday Morning, 9:00 A. M.

Technical Session: R. F. Schuchardt, Chairman.

The Quality Rating of High-Tension Cable, by D. W. Roper and Herman Halperin, Commonwealth Edison Co.

Tests on High-Tension Cable, by F. M. Farmer, Electrical Testing Laboratories.

The Effect of Internal Vacua in High-Voltage Cable, by W. A. Del Mar and C. F. Hanson, Habirshaw Electric Cable Co.

Some Interconnected-System Operating Problems, by F. G. Boyce, Consumers Power Co.

Friday Afternoon, 2:00 P. M.

Technical Session: Arthur Simon, Chairman.

Cooperation Between the Colleges and the Industries in Research

Paper or addresses by:

Wm. E. Wickenden, Society for the Promotion of Engineering Education.

Dean A. A. Potter, Purdue University.

Benjamin F. Bailey, University of Michigan.

Dean Milo S. Ketchum, University of Illinois.

Edward Bennett, University of Wisconson.

Behavior of Radio Receiving Systems to Signals and to Interference, by L. J. Peters, University of Wisconsin.

Saturday Morning

Inspection trips: Cars and guides will be provided for trips to points of interest for those who are unable to take advantage of the trips arranged for Thursday afternoon.

Niagara Regional Meeting May, 26-28

High-grade technical sessions and some unusual entertainment features mark the program of the Regional Meeting which will be held at Niagara Falls, N. Y., May 26-28, under the direction of the Northeastern District of the Institute. The new Niagara Hotel will be headquarters for the meeting.

The technical subjects to be presented include measurement of power factor in dielectrics, transmission, tests of hydroelectric units, speed measurements, rectifiers, transformer design, radio-wave propagation, armature reactance, magnetic-flux measurements, supervisory control, fire protection for generators, etc. A list of the proposed papers is shown in the accompanying tentative program.

A very attractive entertainment program has been arranged, including a trip on Lake Ontario, a scenic and inspection trip in the Gorge, a convention dinner, two interesting lectures and a special illumination of the Falls. Special entertainment features are being planned also for the ladies.

The steamer trip on Lake Ontario is arranged for Wednesday evening, May 26. The party will travel by the Gorge route to Lewiston, where the lake steamer will be boarded. Then a moonlight ride on the lake with dancing for those who desire it will afford enjoyment until a late hour.

A trip down the Niagara Gorge will be made on Thursday afternoon; those taking this trip will see the famous rapids and the whirlpool from both sides of the ravine. Stops will be made at the many points of scenic interest and also at the plants of the Niagara Falls Power Company and of the Hydro-Electric Power Commission of Ontario.

On Thursday evening the convention dinner will be held in the Niagara Hotel and a number of the Institute officers will speak briefly.

Following the dinner there will be given with demonstrations a most interesting lecture on the subject "Modern Reproduction of Sound."

Special Illumination of the Falls

A spectacle of great beauty is planned for Thursday night when the Niagara Falls will be specially illuminated with many changing and moving colors. There will be features of this illumination never before shown.

A piano recital together with one of his unique and entertaining interpretations of the music will be given by Vladimir Karapetoff on the evening of Friday, May 28. The many Institute members who have heard Professor Karapetoff in other recitals know that this will be a delightful event.

If possible, the first showing of the new film of the Niagara Falls Power Company will be made on Friday evening in connection with a lecture on the power development of the Niagara Falls. This film will illustrate the possible future power and scenic development of the Falls.

Application has been made for reduced railroad rates under the

certificate plan. If the rates are granted it is hoped that everyone who travels by rail will get a certificate when purchasing his ticket whether or not he intends to make use of the reduced fare. By getting a certificate he will help make up the 250 certificates necessary to obtain the reduction for those who wish to take advantage of it.

The general arrangements for this meeting are being made under the direction of the Coordinating Committee of the Northeastern District of the A. I. E. E. which is as follows: H. B. Smith, Vice-President in Northeastern District; A. C. Stevens, Secretary; J. R. Craighead, E. D. Dickinson, J. A. Johnson, A. E. Soderholm and A. W. Underhill, Jr. The local arrangements are in charge of a committee of which J. A. Johnson is chairman.

TENTATIVE PROGRAM OF NIAGARA FALLS REGIONAL MEETING MAY 26-28, 1926.

Wednesday Morning and Afternoon, May 26

Technical Session—Symposium on Dielectrics and Power-Factor Measurements.

The Power Factor of Dielectrics and Insulation, by J. B. Whitehead, Johns Hopkins University.

The Mechanism of Breakdown of Dielectrics, by P. L. Hoover, Harvard University.

Standards for Measuring Power Factor of Dielectrics, by H. L. Curtis, Electrical Testing Laboratories.

The Significance of Errors in Dielectric-Loss Measurements, by C. F. Hanson, Habirshaw Electric Cable Co.

Use of Dynamometer Wattmeter for Measuring Dielectric Power Loss, E. S. Lee, General Electric Co.

Commercial Dielectric-Loss Measurements, by R. E. Marbury, Westinghouse Elec. & Mfg. Co.

Three Methods of Measuring Dielectric Power Loss and Power Factor, by C. D. Doyle and E. H. Salter, Electrical Testing Laboratories.

Compensation for Errors of the Quadrant Electrometer, by D. M. Simons, Standard Underground Cable Co.

The Dielectric-Loss-Measurement Problem, by B. W. St. Clair, General Electric Co.

Zero Method of Measuring Power with a Quadrant Electrometer, by W. B. Kouwenhoven and P. L. Betz, Johns Hopkins University.

Wednesday Afternoon and Evening

Special cars will leave for Lewiston following the afternoon technical session, for the steamer trip on Lake Ontario. Executive committee and other committee meetings will be held on the boat.

Thursday Morning

Technical Session

Rectifiers and Their Auxiliary Devices, by O. K. Marti, Cornell University.

Rectifier Voltage Control, by D. C. Prince, General Electric Co.

Radio-Wave Propagation, by E. F. W. Alexanderson, General Electric Co.

Circulation of Harmonics in Transformer Circuits, by T. C. Lennox, General Electric Co.

A Flux-Voltmeter for Magnetic Tests, by G. Camilli, General Electric Co.

Thursday Afternoon

Scenic Trip in the Gorge and Inspections of Power Plants

Thursday, 6:30 P. M.

Convention Dinner

Thursday Evening

After the dinner will come the lecture "Modern Reproduction of Sound" and following the lecture the special illumination of Niagara Falls.

Friday Morning

Technical Session

Variable Armature Leakage Reactance, by V. Karapetoff, Cornell University.

Fire Protection for A. C. Generators, by J. A. Johnson, Niagara Falls Power Co. and E. J. Burnham, General Electric Co.

Automatic and Supervisory Control of Hydroelectric Generating Stations, by F. V. Smith, Westinghouse Elec. & Mfg. Co.

Tests on Niagara Falls Hydroelectric Units, by J. A. Johnson, Niagara Falls Power Co.

Speed Measurements of Rotating Machines, by P. A. Borden, F. K. Dalton and H. S. Baker, all of the Hydro-Electric Power Commission of Ontario.

Friday Afternoon

Technical Session on Power Transmission

Interconnection and Superpower, by S. Q. Hayes, Westinghouse Elec. & Mfg. Co.

European Transmission Practises, by G. F. Chellis, Whitehall Securities Corp.

Lightning and Other Experience on 132-Kv. Transmission Lines, by M. L. Sindeband and P. S. Sporn, American Gas and Electric Co.

Notes on the Vibration of Transmission-Line Conductors, by Theodore Varney, Aluminum Co. of America.

Transmission-Line Sag Calculations, by H. B. Dwight, Massachusetts Institute of Technology.

Friday Evening

Piano Recital, Vladimir Karapetoff

Lecture on the *Power Development of the Niagara Falls*, Illustrated with motion pictures.

April 13th Meeting of I. E. C. to be Addressed by Prominent European Engineers

On the evening of the first day of the coming plenary session of the International Electrotechnical Commission which is to be held in New York, April 13th to 22nd, a general meeting is scheduled for the Auditorium, Engineering Societies Bldg., 33 West 39th St., New York, which should prove of great interest to all engineers. The program for the evening calls for the opening of the meeting by Dr. C. O. Mailloux, Honorary President of the I. E. C. He will then introduce Dr. Clayton H. Sharp, President of the United States Committee. Dr. Sharp will turn the meeting over to John W. Lieb, Chairman of the Reception Committee who will call upon Professor Elihu Thomson to make the address of welcome to the foreign delegates. There will be a brief response by Colonel R. E. Crompton, C. B., Honorary Secretary of the Commission. Brief address will be given by representatives of France, Poland, Germany, Scandinavia and Japan. The principal address of the evening will be made by Guido Semenza of Milan, Italy, President of the International Electrotechnical Commission on "The Accomplishments and Aims of the International Electrotechnical Commission."

An outline of the program for the entire week was given in the March Journal, page 297.

Doctor R. A. Millikan to Speak on "High-Frequency Cosmic Rays"

The members of the New York Section of the A. I. E. E. and the New York Electrical Society are to have the wonderful opportunity of again listening to an address by Dr. R. A. Millikan, Director, Norman Bridge Laboratory, California Institute of Technology. Dr. Millikan will describe his recent work in

the detection of "High-Frequency Cosmic Rays," carried on at Lake Muir at the summit of Mt. Whitney and Arrowhead Lake in the San Bernardino mountains, also on Pike's Peak in which he determined that these rays, at first called "penetrating radiation" of the atmosphere, come definitely from above. The shortest wave length determined corresponds to a frequency 10,000,000 times higher than that of visible light and that the computed frequencies correspond closely to the energy involved in the simple capture of an electron by a positive nucleus.

Dr. Millikan, as those who have had the pleasure of listening to his previous talks know, can present an intricate and difficult subject in a way which all can understand. He has been the recipient of, among numerous other awards, the Edison Medal in 1922 and the Nobel Prize of the Swedish Academy in 1923.

The meeting will be held in the Auditorium, Engineering Societies Building, 33 West 39th Street, New York, at 8 p. m., on Saturday evening, April 10, 1926.

New York Section to Hold Student Convention

The New York Section will hold its first Student Convention on Friday, April 23, 1926. The plans for this convention have been under way for some time, through conferences of N. Y. Section officers and a committee representing the student body of the eight colleges within the New York Section territory, as follows: College City of New York, Columbia, Cooper Union, New York University, Newark College of Engineering, Polytechnic Institute of Brooklyn, Rutgers University and Stevens Institute of Technology.

The morning of April 23rd will be devoted to inspection trips to the G. E. Lamp Works at Harrison, N. J.; the Bell Laboratories, and the I. R. T. repair shops. An afternoon session in Room 1, Fifth Floor, Engineering Societies Building, 33 West 39th St., New York, will start at 2:30 p. m. with one student speaker from each of the eight colleges. President Pupin will give a short address. A get-to-gether supper will follow at the Fraternity Club. Tickets to be sold at $1.50 each.

The evening program is being arranged by the New York Section officers and is to be of particular interest to students. The session will be held in the Auditorium at 8:15 p. m. Definite announcement of speakers will be made later.

Future Section Meetings

Baltimore

Talk by a Member of the Local Section. Engineers' Club. April 16, 8:15 P. M.

Induction Interference, by H. S. Phelps. Engineers' Club. May 21, 8:15 P. M.

Cincinnati

Electrical Control Equipment, by Mr. Wilms, Allen-Bradley Co. April 8.

Connecticut

Bay of Fundy. New Haven. April 9.

Radio. Bridgeport. April 29.

Detroit Ann Arbor

Motors, Power Factor and Power-Factor Rates, by E. L. Bailey, Cleveland Electric Motor Co. April 23.

Lehigh Valley

Oil Switches, by G. A. Burnham, Condit Electric Mfg. Co., and *Horsepower*, by J. J. Johnson, Westinghouse Electric & Mfg. Co. Hazleton. April 23.

St. Louis

Automatic Stations, by C. A. Butcher, Westinghouse Electric & Mfg. Co. April 21.

Automatic Telephoning in St. Louis. May 19.

Spring Meeting of the American Society of Civil Engineers

On April 14th, at Kansas City, Mo., the American Society of Civil Engineers will open the program of its Spring Meeting with the subject on the Relation of the Railroads to Modern Highway and Urban Traffic. This will be followed on Wednesday by an important session on the question of Urban and Interurban Busses, and on Thursday, April 15th, the Technical Divisions will hold sessions in their various fields. Programs have been arranged by the City Planning, Construction and Sanitary Engineering Divisions, with the presentation of two important papers and discussion thereon. In addition to the comprehensive technical program, a number of delightful social events and sightseeing and inspection trips are planned. The dinner dance will be held in the roof garden and ball room of the Kansas City Athletic Club. The Official program is now available to any wishing to review a copy.

Important Meeting of New England Engineers

With all New England engineering interests joining heartily in the support and promotion of its success, the program of the Providence Sections of the American Society of Mechanical Engineers is being completed for a gigantic gathering of professional interests May 3-6, 1926. The opening session of the meeting will have for its subject Industrial Education, followed, Tuesday morning, by a session on Small Parts Manufacture, Industrial Power and Wood Industries; Wednesday morning's sessions will be devoted to Cold-working of Metals, Central Power Stations Problems and Textiles. Some features for which arrangements have already been consummated include visits to the Narraganset Electric Lighting Company, Brown & Sharpe Mfg. Co., the Providence Gas Company and selected textile and rubber plants. Entertainments will be a reception Monday evening, a men's luncheon Tuesday, a Rhode Island Clam Bake Tuesday evening and an informal dinner Wednesday. On Thursday, the party will visit the Newport Torpedo Station and will be afforded the unusual opportunity of seeing the torpedoes launched and visiting will also include an inspection of the shops, training station, the old battleship, Constellation and Newport itself.

Student Convention at Swarthmore

The second annual student convention of the Philadelphia Section of the A. I. E. E., held at Swarthmore College on Monday, March 8th, was an eminently successful continuation of last year's pioneer event. Two hundred and twenty-nine students of electrical engineering, from Delaware, Drexel, Haverford, Lafayette, Lehigh, Pennsylvania, Princetown, Swarthmore and Villa Nova, met for a convention run by themselves on lines quite like those of regular A. I. E. E.

After inspection of the laboratories, the morning sessions were opened by an address of welcome by Dr. Lewis Fussell, Professor of Electrical Engineering, who immediately turned the session over to E. D. Gailey, '26, Chairman of the Swarthmore College Branch. A varied program of four papers drew forth a lively discussion and absorbed the attention of all. This morning session comprised the following papers:

Recent Developments in Power Plants, Herbert Estrade, University of Pennsylvania, 1926

Electricity in Motion-Picture Theatres, F. G. Kear, Lehigh University, 1926

Electron Theory as Applied to the Discharge Tube, Irvin A. Travis, Drexel Institute, 1926

Some Recent Developments in the Incandescent-Lamp Industry, Homer A. Blake, University of Delaware, 1926.

Luncheon, as guests of Swarthmore, was followed by inspections

of buildings and campus, and at 2:30 four parties left by auto for trips of inspection to the following plants:

Chester Waterside Plant of the Delaware County Electric Co., Chester, Pa.

South Philadelphia Works of the Westinghouse Electric and Manufacturing Company, Lester, Pa.

Pine Ridge Automatic Substation, Philadelphia and West Chester Traction Co., Pine Ridge, Pa.

Baldwin Locomotive Works, Eddystone, Pa.

The laboratories were open again from 6 to 7, at which time students and many men of the Philadelphia section learned how complete an equipment is available in this small college. The dinner, of which 119 partook, and the evening session attended by 180, constituted the regular March meeting of the Philadelphia Section, with C. D. Fawcett, past-chairman, in charge. He introduced National Secretary F. L. Hutchinson, who spoke in a most illuminating way of "Institute Activities," pointing out the numerous ways in which the student and the Institute can be mutually beneficial.

Farley Osgood, consulting engineer, and Past-President of the A. I. E. E., spoke in his forceful way on "College—Then What?" bringing clearly to the most casual student the idea that his place in the world is what *he* will make it, and that a technical education is the best possible preparation for any kind of life. A number of interesting "stunts" were then presented, dancing, music, etc., and the day was brought to a close with a few remarks by Dr. Fussell. He stressed the fact that the success of the convention type of meeting, in which the Philadelphia Section is the pioneer, is now established and should innsure its continuance as an annual event.

The Student Branch Activities Committee, consisting of Professor Morland King of Lafayette, Professor L. H. Rittenhouse of Haverford, Professor Malcolm Maclaren of Princeton, Professor J. G. Brainerd of University of Pennsylvania, Professor Dean Tanzer of Drexel Institute, and Professor L. Fussell of Swarthmore, Chairman, and the local committees under Mr. Gailey deserve great credit for perfecting the details of an extremely well thought out and smooth running convention.

Adoption of Metric System Discussed

The House Committee on Coinage, Weights and Measures opened hearings in Washington, March 4th, on a bill which proposes to make the metric system effective in this country after January 1935. While opposition as well as approval of the bill was expressed by representative men, it is generally contended that the ultimate good to be derived from the adoption of a universal unit of measure is obvious, in view of which the earlier it is put into effect the sooner will the whole situation be simplified. As Major Fred J. Miller, past-president of the A. S. M. E. expressed it, "A gram of prevention is worth a kilogram of cure." Some of those opposing the bill were Luther D. Burlingame, chairman of the A. S. M. E. Committee on Standardization and Unification of Screw Threads, other representatives of the A. S. M. E. on the National Screw Threads Commission and C. C. Stutz, Secretary of the Institute of Weights and Measures, while the passage of the bill was supported by S. W. Stratton, Gano Dunn, Thomas A. Edison, General Pershing, Samuel Vauclain, and others of representative prominence.

Doctor Whitehead Chosen Exchange Professor to Lecture in France

Doctor J. B. Whitehead, Dean of Engineering of Johns Hopkins University, and a Director of the A. I. E. E., has been selected by seven American universities as their international exchange professor to France. His appointment was made under an arrangement among Harvard, Yale, Columbia, Cornell, University of Pennsylvania, Massachusetts Institute of Technology, Johns Hopkins and the French Government to establish an exchange professorship of engineering and applied science for the two countries.

The course of lectures to be given by Doctor Whitehead at the French universities which he will visit during the first half of 1927, will deal with the subject of "Insulation and the Dielectric Theory." Doctor Whitehead is known throughout the world for his research on the problems of insulation, having delivered many papers on this subject before the A. I. E. E. His research on high-voltage insulation received recognition in Europe last year when he was awarded a triennial prize of the George Montefiore Foundation of Belgium for his series of papers on "Gaseous Insulation in Built-up Insulation." He also received this prize in 1922 for another paper on "The Corona Voltmeter and the Electric Strength of Air." Among other honors for papers in the same general field was his recent receipt of the Longstreth Medal of the Franklin Institute.

This professorship was established at the close of the war for the purpose of exchanging knowledge between France and America through interchanging professors of outstanding ability. Dr. A. E. Kennelly, Professor of Electrical Engineering, Harvard University, Past-President of the Institute, was the first American selected for this exchange (1921-22). During the last four years three other American scientists have had this honor, namely: Dr. E. M. Chamot, professor of Sanitary Chemistry, Cornell University; Dr. D. W. Johnson, Professor of Physiography, Columbia University, and Dr. John Frazer, Dean of the Towne School of Engineering, University of Pennsylvania. In the same period Prof. J. Cavallier, Recteur, University of Lyons; Prof. Emmanuel de Margerie, Geologist, University of Strasbourg, and Prof. Pierre Lemaire, Professor of Mechanical Enginering, University of Lyons, have come from France to the United States.

John Ericsson Medal Established

A gold medal to be known as "The John Ericsson Medal" and to be awarded to Americans of Swedish birth or descent, or to Swedish citizens, as a recognition of distinguished accomplishments in science and engineering, was established in January 1926 by the American Society of Swedish Engineers. This medal which was established in honor of the great engineer and scientist, Ericsson, will be awarded not oftener than once in two years on a recommendation of a medal committee comprising four members each of the Swedish Academy of Engineering Science and the American Society of Swedish Engineers.

The first award will be made at the time of unveiling the John Ericsson monument in Washington, D. C., in May. The American Society of Swedish Engineers, which has headquarters in Brooklyn, N. Y., was founded in 1888 and has a membership of approximately 500.

Medal for Radio Amateurs

A medal for those who serve humanity through radio by bringing aid in time of peril has been offered by the magazine *Popular Radio*. The awards will be made to non-professionals through whose efficient action radio is utilized to alleviate suffering or save life within the territory and waters of the United States.

Those who qualify for this recognition should be brought to the attention of the Committee of Awards, Popular Radio Medal for Conspicuous Service, 627 West 43rd Street, New York.

A World Language For Electricity

Plans to formulate a universal language for electricity will come before a ten-day plenary convention of the International Electrotechnical Commission to be held in New York beginning April 13th, as announced by Doctor Clayton Halsey Sharp, president of the United States Committee of the Commission. National committees of the Commission in America, Great

Britain and countries of the Continent have been developing studies in this field and their reports will be submitted at this meeting, the first to be held in this country. Radio expansion, it is declared, has increased the demand for common terms and symbols, and steps have already been taken as a part of the general program for worlds standards, to meet this situation in an electrical language. An international dictionary of electrical terms is also one of the aims of the Commission.

A. I. E. E. Year Book

The 1926 issue of the Year Book goes to press about April 1st and copies will be available for distribution shortly thereafter.

The book contains an alphabetical and geographical catalog of the membership, revised to January 1, 1924; also the constitution, by-laws, lists of officers and committees, and much additional information relating to the activities of the Institute.

New York Section Nominations for 1926-27

The Nominating Committee of the New York Section has named the following ticket for officers of the New York Section for the year 1926-27: Chairman, E. B. Meyer, Public Service Electric Co.; Secretary-Treasurer, O. B. Blackwell, American Telephone and Telegraph Co.; Executive Committee, J. B. Bassett, General Electric Co. and C. R. Jones, Westinghouse Elec. & Mfg. Co. Mr. H. A. Kidder, the present chairman, automatically becomes Junior Past Chairman on August 1st and makes the fifth member of the Executive Committee. The ballots for the above ticket are now before the Section membership and final results will be announced at the April 23rd meeting of the Section.

PERSONAL MENTION

Frederick W. Walker has closed his Chicago office, and, effective March 1st, 1926, has been appointed vice-president of the Northwestern Mutual Life Insurance Company, Milwaukee, Wis.

Joseph Rogoff, who was industrial engineer for the Salt's Textile Company, Inc., Bridgeport, Conn., has been appointed superintendent of the Gaynor Electric Company, Inc., of that city.

Bertram Wardle, who was chief draftsman for the English Electric Co. of Canada, Ltd., has recently identified himself with the Canadian General Electric Co., Peterboro, Ontario, Canada.

W. J. Moulton-Redwood, of the engineering staff of the Canadian National Carbon Company and the Prest-O-Lite Company of Canada, has resigned from these interests and gone to Auckland, N. Z., for Commercial engineering work.

J. Maldonado, formerly electrical engineer for the Brooklyn Edison Company, has signed a contract with the Worthington Pump and Machinery Corporation of New York and will assume the managership of their Barcelona Offices, Compania de Bombas Worthington, Plaza Universidad, 2, Barcelona, Spain.

George L. DeMott, after seven years' service as examiner in the United States Patent Office in charge of the Electrical Measuring Instrument art and having completed a four years' course in law in addition to his previous technical training, has become associated with the Union Switch and Signal Company of Swissvale, Pennsylvania, as assistant patent counsel.

S. R. Williams, formerly special representative of the Westinghouse Electric and Manufacturing Company, with headquarters at South Bend, Indiana, has been appointed their street lighting engineer at Boston. Mr. Williams was also at one time connected with the Philadelphia office of the company, assisting in the sale of street lighting equipment. He is a graduate of the Westinghouse student sales and engineering course.

H. J. E. Reid, an Associate of the Institute, on January 1, 1926, was appointed Engineer-in-charge of the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics at Langley Field, Virginia. Mr. Reid received his engineering education at Worcester Polytechnic Institute and for the past five years has been chief of the Instrument Section of the laboratory of which he is now in charge. He has the honor of being the youngest man to receive appointment to such an important position in aeronautical research.

Obituary

Albert Cavallo Jewett, who joined the Institute in 1906 and the following year was elected to Life Membership, died on February 3d, 1926, at Papeete, on the Island of Tahiti. Mr. Jewett was born in Henderson County, Kentucky, December 20th, 1869, and for four years after he was of eligible age, studied under a private tutor. His technical education was acquired while he was in the employ of the General Electric Company. From 1890 to 1892 he was with the Thomson Houston Electric Company, Colorado and California, after which he spent a year with the General Electric Company. In December of the year 1903 he went to Messrs. John Taylor & Sons, London, England and from then, the first of December 1905, entered the employ of H H. The Maharajah, Jammu and Kashmir, as electrical advisor to the Government of India. The installation of the original Redlands transmission line was done by Mr. Jewett in 1893, and this was followed by the installation of many other equally important systems in California districts up to the year 1900.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—William E. Ames, Detroit Edison Co., Detroit, Mich.
2.—H. R. Bailey, Electric Bldg., Portland, Ore.
3.—I. Bergenstrahle, 425 West 114th St., New York, N. Y.
4.—Hubert L. Clary, 782 West 24th St., Milwaukee, Wis.
5.—J. E. Contesti, 350 W. 58th St., New York, N. Y.
6.—Ralph Elsman, 120 Broadway, New York, N. Y.
7.—Chas. A. Foust, 10505 93rd St., Woodhaven, N. Y.
8.—George Frasher, 1209 So. 4th Ave., Louisville, Ky.
9.—S. Alden Griffin, 19 Elliott St., Springfield, Mass.
10.—Harold G. Haines, 7416 Sylvester, Detroit, Mich.
11.—Elmer D. Johnson, 1481 Harvard St., Washington, D. C.
12.—Charles L. Leaf, 175 Dodd St., East Orange, N. J.
13.—John E. Lewis, 376 Meyran Ave., Oakland Sta., Pittsburgh, Pa.
14.—Charles W. Magee, c/o Pelser, 210 West 102nd St., New York, N. Y.
15.—J. A. McDermott, Y. M. C. A., Lima, Ohio.
16.—Raymond W. Noddins, 230 East Ohio St., Chicago, Ill.
17.—G. C. Poulson, 500 Danforth St., Syracuse, N. Y.
18.—Robert H. Russell, 1128 Warren West, Detroit, Mich.
19.—Lieut. A. G. Scott, 68 West 107th St., Apt. 2D, New York, N. Y.
20.—Kermit G. Seaman, P. O. Box No. 68, Boulder, Colo.

21.—A. B. Smedley, c/o Cooper Hewitt Elec. Co., 1406 First Nat'l Bank, Cincinnati, Ohio.
22.—C. D. Smith, 857 St. Charles St., New Orleans, La.
23.—Will M. Strickler, 301 Detroit Life Bldg., Detroit, Mich.
24.—Howard J. Tyzzer, 13 Upham St., Melrose, Mass.
25.—Leo A. VanEtsen, 1100 Park Ave., New York, N. Y.
26.—John D. Walker, 2686 Woodstock Ave., Swissvale, Pa.
27.—A. R. Williamson, 561 Delaware Ave., Norwood, Pa.
28.—I. H. Worley, 2124 E. St., Lincoln, Nebr.
29.—M. L. Younger, 1814 Diamond St., Philadelphia, Pa.

Extracts from Annual Report for 1925

The year has been one of steady operation, unmarked by unusual occurrences. The number of users of the Library was practically the same as in 1924, amounting to about 70% of the membership of the Founder Societies.

The budget adopted for 1925 called for the expenditure of $44,200 for the general maintenance of the Library. The actual expenses were $41,176.89. But while the cost has been kept within the budget, this should not be taken as an indication that more money should not be appropriated for Library work. To accomplish this result, it has been necessary to decline to undertake many activities that are desired by members and that would be permanent improvements.

There is, for example, a distinct need for more ample indexing of the output of current periodical literature. This has reached the point where few engineers can afford the time necessary to examine it; as a consequence they must rely upon bibliographies and abstracts to guide them. Here there is a wide field for developments that would be useful to every member.

There have also been opportunities during the year to purchase private libraries of unusual importance, which could not be accepted. Similar opportunities will undoubtedly again arise from time to time, and it is highly desirable that your Board be in a position to take advantage of them.

Your Board constantly regrets its inability to develop the work in these and other ways that are suggested from time to time. It realizes, however, that its first duty is to restrict the cost of its operations to the sums set apart for the purpose and so confines the work to what can be done with the funds available.

The equipment of the Library is generally in satisfactory condition.

During the year the lighting of the reading room was investigated and found below the best practise of the day. Methods for its improvement are now being studied.

The accessions during 1925 and the book stock on 31 December, 1925, are as follows:

	Vols.	Pamphlets	Maps	Searches	Total
On hand Jan. 1, 1925	100,111	4,001	1,641	3,991	109,744
Added during 1925	3,746	818	159	129	4,852
Total	103,857	4,819	1,800	4,120	114,596
Withdrawn during 1925	2,828	1,449	——	——	4,277
Net accessions, 31 Dec., 1925	101,029	3,370	1,800	4,120	110,319

FINANCIAL STATEMENT
31 DECEMBER, 1925

Maintenance

REVENUE		
Founder Societies	$32,000.00	
Associate Societies	1,200.00	
Endowment Income (net)	4,883.33	
Book Loans	284.51	
Miscellaneous	175.00	
		$38,542.84
EXPENDITURES		
Salaries: Maintenance	$31,625.20	
Books	1,367 71	
Book Loans	265.86	
Periodicals	2,844.88	
Binding	2,554.85	
Supplies and Miscellaneous	1,355.57	
Equipment	190.57	
Insurance	972.25	41,176.89
Operating Deficit Dec. 31, 1925		2,634.05
Special Contributions		2,634.05
Operating Balance Dec. 31, 1925		0.00

Service Bureau

REVENUE		
Search Department	$7,776.37	
Photostat Department	6,839.12	
Miscellaneous	.50	
		$14,615.99
EXPENDITURES		
Salaries, searchers	8,319.60	
Salaries, photographers	4,330.94	
Supplies, search	688.46	
Supplies, photographic	1,808.85	15,147.85
Operating Deficit		$ 531.86
Credit Balance Dec. 31, 1924	$1,398.12	
Less Accounts charged off and adjusted (net)	10.01	
		1,388.11
Credit Balance Dec. 31, 1925		$ 856.25
Accounts Receivable Dec. 31, 1925		$ 830.67

Book Reviews

THE RELAY HANDBOOK.

Prepared by the Relay Subcommittee, Electrical Apparatus Committee, and Technical National Section of the National Electric Light Association in collaboration with the Relay Subcommittee and Protective Devices Committee of the American Institute of Electrical Engineers, a volume to be known as the Relay Handbook is now available through the offices of the National Electric Light Association, Engineering Societies Building, New York.

The first point of the book is given over to many valuable tables of carefully computed engineering data, followed by text descriptive of relays and their uses, tests and maintenance and concluded with information of calculations applying to the subject. There is also an extensive bibliography, arranged sectionally and in chronological order under the several important heads. The possibilities of protecting electrical systems from faults involving the energy within the system have made such marked progress within recent years has made the publishing of the present handbook a great asset to the profession. The increasing size and extensive interconnection of the systems is also safeguarded in this publication of theory as well as practise. It reduces a volume of data to usuable form, well proportioned with regard to scope, authority and comprehensiveness.

POPULAR RESEARCH NARRATIVES.

Volume II of "Popular Research Narratives" has been published through the Engineering Foundation, 29 West 39th Street, New York. From the preface "Mankind must progress or regress—let us go forward seeking the truth and using it for the betterment of all mankind" is best descriptive of the effort and purpose of the work, which is a collection of fifty brief stories of research, invention and discovery by such eminent scientists as Doctor

M. I. Pupin, H. C. Hayes, Major General George O. Squier, Chief Signal Corp of the U. S. Army, Doctor Arthur E. Kennelly, Member of the National Academy of Sciences; Chevalier Legion d'Honneur, William G. Houskeeper, Research Laboratories of the American Telephone and Telegraph Company, Sir Ernest Rutherford, President of the British Association for the Advancement of Science, Messrs. Arnold and Elmen of the Research Laboratories of the American Telephone and Telegraph Company and the Western Electric Co., Inc., and many others who have contributed greatly to the research and application of science. The book is a convenient size, 5 x 7, contains 160 pages and sells for $1.00.

THE FUNDAMENTAL CONCEPTS OF PHYSICS in the Light of Modern Discovery. Williams & Wilkins, Baltimore, Md.

This work, by Paul R. Heyl, Ph. D., Physicist, Bureau of Standards, Washington, contains three lectures: The Eighteenth Century: The Century of Materialism; The Nineteenth Century; The Century of Correlation; and The Twentieth Century; The Century of Hope. 112 pages. Size of Volume 5 x 7. Price $2.00.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (FEBRUARY 1-18, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ANNUAIRE POUR L'AN 1926.

France. Bureau des Longitudes. Paris, Gauthier-Villars, 1926. 665 + 337 pp., 6 x 4 in., paper. 8 fr.

The 1926 edition of this well-known reference book contains the usual collection of data on the calendar, the earth, astronomy, weights and measures and physical and chemical constants, and is a valuable compilation of information frequently wanted by physicist, chemists, astronomers, etc. In addition it contains a lengthy account of the International Research Council and the Astronomical Union, by B. Baillaud, and an article by G. Pervier, entitled the Geodesic Reasons of Terrestrial Isostasy.

DAS DEUTSCHE PATENTRECHT.

By F. Damme and R. Lutter. 3rd edition. Berlin, Otto Liebmann, 1925. 692 pp., 9 x 6 in., paper. 28.-mk.

A new edition of a standard text on German patent law and practise, prepared by a former and the present director of the Patent Office. The discussion is comprehensive and practical as well as thoroughly up to date.

DIESEL MASCHINEN. Sonderheft, V. D. I. Zeitschrift 1925. 97 pp., illus., diagrs., plates.

ENTGASEN UND VERGASEN. Sonderheft, V. D. I. Zeitschrift, Bd. 69. 116 pp., illus., tables.

TECHNISCHE MECHANIK. Ergänzungsheft, V. D. I. Zeitschrift, Bd. 69. 84 pp., illus., diagrs.

Berlin, V. D I., Verlag, 1925-26. 3 vols., 12 x 8 in., paper. Prices not quoted.

These three publications contain collections of important articles on their various subjects, selected from recent issues of the Zeitschrift des Vereines deutscher Ingenieure and reprinted in this form for convenient use. The volume on Diesel engines contains articles on the Diesel locomotive from the viewpoint of locomotive construction, Diesel engines and gearing for large oil locomotives, high speed Diesel engines for vessels, compressorless Diesel engines, etc.

The volume entitled "Entgasen und Vergasen" considers various problems of fuel preparation and utilization. Among these are coal dressing, gas distribution, the improvement of coking coal at the mine, dry cooling of coke, the distillation of low-grade fuels, the Lurgi distillation process, the mechanical influence of fuel in gas generators, and new knowledge in firing practice.

Among the papers on technical mechanics are a criticism of thermal engines, heat transfer from oil to water and loss of pressure in cooling apparatus, heat transmission and loss of pressure in pipe coils, parallel flow and turbulence in circular pipes, resistance to flow in pipes, errors in the measurement of the temperature of flowing gases, fine measuring tools for tension in machine parts, the solution of statically indeterminate systems by means of the Nupubest instrument.

ECLAIRAGE ELECTRIQUE.

By P. Maurer. Paris, Gauthier-Villars et Cie., 1925. 143 pp., diagrs., 10 x 6 in., paper. 20 fr.

A text-book on electric lighting which is confined to a brief presentation of fundamental theory and of its application in practice. The author first discusses general principles and photometry. He then studies the different types of incandescent and arc lamps, after which he takes up the layout of lighting for various types of buildings. The final section is devoted to the installation of interior lighting systems.

ELECTRIC RAILWAY ENGINEERING.

By C. Francis Harding and Dressel D. Ewing. 3rd edition. N. Y., McGraw-Hill Book Co., 1926. 489 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

A textbook for students in technical schools who wish to specialize in electrical railway engineering, in which present theory and practice in the important branches of the subject are brought together in convenient form.

The new edition has been completely revised and enlarged. A new chapter on motor-bus transportation has been added. The chapter on "Power Station Location and Design" has been replaced by one entitled "Sources of Electrical Energy," which contains a recent, very complete contract for electrical energy.

ELEKTROMETALLURGIE.

By K. Arndt. Berlin u. Leipzig, Walter de Gruyter & Co., 1926. 124 pp., illus., 6 x 4 in., cloth. 1,50 mk.

A brief review of the subject written in easily understood language. After a short introductory account of electrochemical principles, the author describes the recovery of copper, the precious metals, zinc, lead, tin, iron, etc., from aqueous solutions. The production of aluminum, magnesium, sodium, etc., by the electrolysis of fused salts is then described. The final section discusses the electrothermal processes for producing iron and its alloys.

ELEMENTARY ELECTRICAL TECHNOLOGY FOR ENGINEERING STUDENTS.

By A. M. Parkinson. Lond., Oxford University Press, 1925. 179 pp., 8 x 5 in., cloth. $2.00. (Gift of Oxford University Press. American Branch).

Confined to the elementary technology of electric circuits and aimed to present the principles as simply as possible, this book is intended to furnish the fundamental theory required as a foundation for a three or four years' course in applied electricity.

ELEMENTS OF ALTERNATING CURRENTS AND ALTERNATING CURRENT APPARATUS.

By J. L. Beaver. N. Y., Longmans, Green & Co., 1926. 370 pp., illus., diagrs., 9 x 6 in., cloth. $4.00 (Gift of Author).

A textbook for beginners in the study of alternating currents. The first eight chapters give an elementary presentation of principles, while the remaining four study the commonest types of alternating-current apparatus. Questions and numerical problems are appended to each chapter. The book is planned for a course of sixty to ninety hours.

FESTSCHRIFT ANLASSLICH DES 100 JAHRIGEN BESTEHENS DER TECHNISCHEN HOCHSCHULE FRIDERICIANA ZU KARLSRUHE. Karlsruhe, C. F. Müller, 1925. 542 pp., illus., diagrs., tables, 10 x 7 in., ¾ cloth.

A handsome volume commemorating the centenary of the oldest technical college in Germany. It contains 38 papers by members of the faculty, dealing with various subjects—mathematical, economic, mechanical, electrical, chemical and physical. A history of the beginnings of technical education is included.

Among the papers of especial interest to engineers are: Simplification of arch calculations, Methods of colonizing, City planning and building as a province of engineering, The influence of repeated loads on the elasticity and strength of concrete and reinforced concrete, Band spring drives, Calculation of shearing stress produced by punching, Heat transmission to water in a tube, Experiments on the straightening of crooked rods, Safety and economy of electric power transmission.

GALVANIZING.

By Heinz Bablik. Lond., E. & F. N. Spon; N. Y., Spon & Chamberlain, 1926. 168 pp., illus., tables, 9 x 6 in., cloth. $5.00.

As the manager of a large Austrian galvanizing works, the author has carried out various scientific investigations on the subject, which are assembled in this book. His purpose is to explain, in the light of modern scientific conceptions, processes already known in outward form.

Opening with a discussion of rust and its prevention, succeeding chapters deal with the structure of galvanized coatings, pickling, fluxes, hot galvanizing, raw materials and waste products, electro-galvanizing, sherardizing, metal spraying, and the testing of products.

MODERN MAGNETICS.

By Felix Auerbach. N. Y., E. P. Dutton & Co., 1925. 306 pp., diagrs., 9 x 6 in., cloth. $6.00.

Professor Auerbach has attempted to give a picture of the present state of the theory of magnetism, complete enough for the needs of every one except the specialist within the limits of one small volume. He has succeeded admirably, having produced a book that will not only interest engineers and teachers, for whom it is primarily intended, but can also be read by any general reader in search of knowledge on the subject. The style is easy and fluent, mathematics is reduced to a minimum, and the text is illustrated by numerous figures. A valuable select bibliography is appended.

POPULAR RESEARCH NARRATIVES, vol. 2; collected by the Engineering Foundation. Baltimore, Md., Williams & Wilkins Co., 1926. 174 pp., ports., 8 x 5 in., cloth. $1.00. (Gift of the Engineering Foundation).

The wide general interest that the first volume of "Research Narratives" excited has led the Engineering Foundation to publish a second volume. Here are fifty brief stories of useful inventions and discoveries, showing how the scientist and engineer proceed in advancing the welfare of mankind. The accounts are written in non-technical language, with unusual brevity, by men of experience in the subjects treated.

PRACTICAL PHOTO-MICROGRAPHY.

By J. E. Barnard and Frank V Welch. 2d edition. N. Y., Longmans, Green & Co., Lond., Edward Arnold & Co., 1925. 316 pp., illus., 9 x 6 in., cloth. $6.00.

A straightforward detailed account of the methods used in photographing microscopic objects, written by experienced workers. The book discusses the microscope, the optical equipment, sources of illumination, cameras, color screws, plates and photographic processes.

PRACTICAL RADIO, INCLUDING THE TESTIHG OF RADIO RECEIVING SETS.

By James A. Moyer and John F. Wostrel. 2d edition. N. Y., McGraw-Hill Book Co., 1926. 271 pp., illus., diagrs., 8 x 5 in., cloth. $1.75.

Attempts to present the fundamentals of the subject so simply and clearly that the average reader may understand and apply them. It also gives working drawings and specifications for the construction of a number of good receiving sets of various types. The new edition has been revised and a number of new subjects treated.

RAILROAD CONSTRUCTION.

By Walter Loring Webb. 8th edition. N. Y., John Wiley & Sons, 1926. 849 pp., illus., diagrs., tables, 7 x 4 in., fabrikoid. $5.00.

In addition to the revision of several chapters to conform with recent practice and the addition of several minor topics that have become important, special attention has been given in this edition to the relations of locomotive power to grade. A more exact method of computation has been introduced in the chapter on locomotive power, which has been rewritten and also used in the chapter on grade to show the effect of undulatory grades on power.

SCIENCE IN THE MODERN WORLD.

By Alfred North Whitehead. N. Y., Macmillan Co., 1925. (Lowell lecturers, 1925). 296 pp., 9 x 6 in., cloth. $3.00.

This volume, by the Professor of Philosophy in Harvard University, is a study of some aspects of Western culture during the past three centuries, in so far as it has been influenced by the development of science. Dr. Whitehead gives a thoughtful analysis of the reactions of science in forming that background of instinctive ideas which control the activities of successive generations. He points out the primary concepts upon which science seated itself during the period under consideration; calls attention to the recent breakdown of the seventeenth century settlement of physical principles and criticizes the current philosophy of scientists.

SIGNAL WIRING.

By Terrel Croft. N. Y., McGraw-Hill Book Co., 1926. 349 pp., illus., diagrs., 8 x 6 in., cloth. $3.00.

As signal wiring is principally a matter of knowledge of circuits, this book is chiefly a collection of circuit diagrams. Over 460 circuits are illustrated, including those usually wanted for wiring bells and annunciators, burglar alarms, hospital and hotel signals, time-clock signals, autocall signals, telephones, fire alarms, police calls, power station signals, water-flow and pressure alarms, elevator, mine, railroad and miscellaneous signals. A chapter is devoted to methods of wiring.

SUPERPOWER, ITS GENESIS AND FUTURE.

By William Spencer Murray. N. Y., McGraw-Hill Book Co., 1925. 237 pp., diagrs., maps, 9 x 6 in., cloth. $3.00.

As the Engineering Chairman of the United States Government Superpower Survey, Mr. Murray is already widely known as an authority on the question of the interconnection of power plants. The present book considers the question from a broader viewpoint than the government report and is intended for a wider audience. Stress is placed upon the social and economic advantages to be gained by "superpower" production and distribution, although the engineering problems are by no means neglected. Throughout, the main purpose is to present the principal features of the problem clearly and logically and to point out the benefits to be expected from "superpower."

TECHNICAL EDUCATION; Its Development and Aims.

By C. T. Millis. N. Y., Longmans, Green & Co.; Lond., Edward Arnold & Co., 1925. 183 pp., 8 x 5 in., ½ cloth. $2.25.

An account of the several movements which have led up to the present position of technical education in Great Britain, with some discussion of the problems that have arisen during its development. Starting with the Mechanics Institutes of 1824, the author traces the history of the various agencies, considers the principles of technical instruction and draws some conclusions.

THEORIE GENERALE SUR LES COURANTS ALTERNATIFS; pt. 2, Les Alternateurs.

By M. E. Piernet. Paris, Gauthier-Villars et Cie., 1926. 145 pp., diagrs., 10 x 6 in., paper. 30 fr.

A complete study, limited to fundamental practical ideas, of the technique of alternating-current machines and circuits.

The book supplements the author's previous work on continuous-currents and is intended for class-room use.

Die Transformatoren.

By Milan Vidmar. 2d edition. Berlin, Julius Springer, 1925. 751 pp., illus., diagrs., 9 x 6 in., cloth. 36 -r.m.

This, the most comprehensive of modern works on the transformer, is distinguished by its thorough grasp of the scientific principles involved and by its illustration of the application of these principles in actual design. The book will be useful to designers especially. The new edition has been carefully revised and considerable new matter has been added.

Les Vehicules Automobiles.

By A. Boyer-Guillon. Paris, J.-B. Baillière et fils, 1926. 378 pp., illus., diagrs., 9 x 6 in., paper. 55 fr.

As head of the testing laboratory of the Conservatoire National des Arts et Métiers, the author of this book has made numerous tests of automobiles. In this work he has acquired a thorough knowledge of the functioning of these vehicles and their organs and has had an opportunity to compare different devices. The results of his experience are presented in this engineering study of the automobile, which presents a number of new points of view.

Wellentelegraphie Und Wellentelephonie.

By M. G. Weinholz. Berlin u. Leipzig, Walter de Gruyter & Co., 1926. 132 pp., illus., diagrs., plates, 9 x 6 in., boards. 3,40 gm.

Intended as a textbook for use in technical and trade schools, where a practical course in radio communication is offered. The treatment is clear and non-mathematical, paying especial attention to the fundamental theory.

Past Section and Branch Meetings

SECTION MEETINGS

Boston

Testing of High-Tension Cable, by F. M. Farmer, Electrical Testing Laboratories. February 19. Attendance 265.

Chicago

The Problem of the Electrical Engineer from the Standpoint of a Physicist, by Max Mason, University of Chicago. Dinner Dance. February 6. Attendance 240.

The Financing of Public Utilities, by M. J. Insull, Middle West Utilities Co. Joint meeting with Electrical Section of the Western Societies of Engineers. March 1. Attendance 215.

Cincinnati

Electric Power Development in the Cincinnati District, by Monroe, Sargent and Lundy. Illustrated with slides. February 11. Attendance 174.

Graphic Measurements in Industry, by D. J. Angus, Esterline-Angus Company. Illustrated with slides. March 11. Attendance 50.

Connecticut

The Value of Patents, by Karl Fenning, Assistant to Attorney General, Department of Justice. February 16. Attendance 18.

Denver

Electrical Transmission of Pictures over Wires , by M. B. Long, Bell Telephone Laboratories, Inc. February 12. Attendance 55.

Detroit-Ann Arbor

D-C. Motor Maintenance, by L. Bogardus. Packard Motor Car Co.,

A.C. Motor Maintenance, by O.R. Candler, Dodge Brothers, Inc., and

Railway-Motor Maintenance, by A. C. Colby, Department of Street Railways. A motion picture, entitled "The Story of the Spark Plug," was shown. January 19. Attendance 125.

Long Telephone Cables, Their Possibilities and Problems, by F. B. Jewett, American Telephone and Telegraph Co. A motion picture showing the inauguration of the Ford Air Transportation Service was shown. February 16. Attendance 110.

Indianapolis-Lafayette

The Use of Graphic Records in Industry, by D. J. Angus, Esterline Angus Co., March 5. Attendance 32.

Ithaca

Hydro-Electric Power Development, by J. A. Johnson, The Niagara Falls Power Co. Illustrated with slides. January 15. Attendance 60.

Steam-Electric Power Development, by F. R. Ford, Philadelphia Electric Co. Illustrated with slides. February 19. Attendance 75.

Kansas City

The Manufacture of Rubber-Covered Wire, by R. J. Wiseman, Okonite Callender Cable Co. Illustrated with slides and moving pictures;

Maintenance of Electrical Equipment in Large Generating Stations, by C. B. Kelley, Kansas City Power and Light Co. February 8. Attendance 39.

Los Angeles

Forecasting Growth of Population an Aid to System Planning, by N B. Hinson, Southern California Edison Co.,

Application of Protective Equipment to Electric Transmission Systems, by E. R. Stauffacher, Southern California Edison Co., and

Steam Generation of Power and the Mercury Vapor Turbine, by F. G. Philo, Southern California Edison Co., March 2. Attendance 187.

Lynn

Social Meeting. March 1. Attendance 400.

Mexico

Technical Publications in the United States, by Mr. Cota. March 4. Attendance 18.

Milwaukee

The Work of the State Highway Department, by J. T. Donaghey, State Highway Engineer. January 20. Attendance 50.

The Vacuum Tube, by R. W. King, Editor of the Bell System Technical *Journal*. February 17. Attendance 500.

Minnesota

Dinner Dance. February 16. Attendance 60.

The Telephone System in Minneapolis, by the Commercial Department of the Northwestern Bell Telephone Co. A motion picture, entitled "The Audion," was shown. March 1. Attendance 100.

Niagara Frontier

Checking the Tuning Fork by Radio, by F. K. Dalton, Consulting Engineer. Illustrated with slides; and

The High-Voltage Air-Insulated Current Transformer, by L. C. Nicholson, Niagara Lockport and Ontario Power Co. Illustrated with slides. Mr. Dalton also gave an account of the destruction of a farm house due to lightning striking a radio aerial. February 19. Attendance 43.

Panama

Automatic Telephones, by J. K. Barrington, Automatic Electric Co. A short talk was also given by W. G. Ferris, Electric Bond and Share Co. February 10. Attendance 26.

Philadelphia

Supplying Electric Power to Downtown Philadelphia, by H. S. Davis and C. L. Gilkeson, Philadelphia Electric Co. Illustrated with slides. February 8. Attendance 180.

Pittsburgh

Voltage-Control Equipment for Interconnecting Power Systems, by J. S. Lennox, General Electric Co. Illustrated with slides. February 16. Attendance 160.

Pittsfield

Volcanoes and Earthquakes, by B. R. Baumgardt. Illustrated with slides. February 16. Attendance 700.

Lighting, by F. W. Peek, Jr., General Electric Co. Illustrated with slides and moving pictures. February 23. Attendance 75.

Ice by Wire—Electric Refrigeration, by W. P. White, General Electric Co. March 2. Attendance 175.

Portland

Social Meeting. February 10. Attendance 210.

Providence

Remote Supervisory Control, by R. J. Wensley, Westinghouse Elec. & Mfg. Co. Illustrated with slides. February 12. Attendance 20.

The Fynn-Weichsel Unity-Power-Factor Motor, by E. W. Goldschmidt, Wagner Electric Corp. March 9. Attendance 40.

Saskatchewan

Rural Electrification in Western Canada, by C. A. Clendening, Power Commission, Province of Manitoba. January 29. Attendance 42.

Turbine Development, by W. W. Johnson, General Electric Co., and

Measuring Output of A-C. Generators, by E. G. Fiske, General Electric Co. February 24. Attendance 40.

Schenectady

Aviation, by Major J. F. Curry, Illustrated with slides. January 22. Attendance 350.

Some Aspects of Corporate Industry's Relation to Society, by C. E. Eveleth, General Electric Co. February 12. Attendance 400.

Rambles in Asia, by B. A. Tozzer, Niles Bement Pond Co. Illustrated with slides. February 26. Attendance 300.

Seattle

Development in Illuminating Streets and Public Thoroughfares, by W. A. Turner, Department of Public Works, and

Transformer Design, by J. G. Corrin, Pittsburgh Transformer Co. Illustrated with slides. February 17. Attendance 52.

Sharon

The Klydonograph, by J. F. Peters, Westinghouse Elec. & Mfg. Co. A Smoker followed the meeting. March 2. Attendance 86.

Spokane

Automatic Substations, by C. E. Carey, Westinghouse Elec. & Mfg. Co. February 19. Attendance 40.

Springfield

The Quest of the Unknown by H. B Smith, Worcester Polytechnic Institute. Ladies Night. February 26. Attendance 100.

Toledo

Late Developments on A-C. Elevators, by E. B. Thurston, Haughton Elevator and Machine Co.;

My Experiences in the Early Days of the Electrical Industry, by Mr. Jeanin, Jeanin Motor Co.; and

Radio Sets, by E. B. Featherstone, Scott and Libbey High Schools. A talk was also given by Gilbert Southern on the functions of the Electric League, now being organized in Toledo to stimulate better wiring of residences. February 26. Attendance 34.

Toronto

International High-Tension Conference, Paris, 1925, by A. E. Davison, Hydro Electric Power Commission of Ontario, February 19. Attendance 65.

Metal Clad-Switchgear, by C. A. Stephens, A. Reyrolle and Company. March 5. Attendance 60.

Utah

The Structure of Atoms, by Dr. Oran Tugman, University of Utah. January 27. Attendance 45.

The Transmission of Photographs over Telephone Wires, by M. B. Long, Bell Telephone Laboratories. February 10. Attendance 70.

Vancouver

Motion Picture, entitled "From Mine to Consumer," was shown. Joint meeting with Engineering Institute of Canada. March 2. Attendance 120.

Washington

Interesting Things about Radio Transmission, by G. C. Southworth, American Telephone & Telegraph Co. Joint meeting with the Washington Academy of Sciences. March 9. Attendance 159.

Worcester

The Quest of the Unknown, by H. B. Smith, Worcester Polytechnic Institute. After the meeting an inspection of the 1,000,000-volt transformer in the laboratory of the Worcester Polytechnic Institute was made. February 23. Attendance 75.

BRANCH MEETINGS

Alabama Polytechnic Institute

Business Meeting. February 3. Attendance 24.

Epoch-Making Engineering Achievement, by Mr. Crawford, student; *The Hudson River, The Tennessee Valley and The Dead Sea Projects*, by Mr. Moore, student; and *Advantages of Electricity on the Farm*, by Mr. Phillips, student. February 18. Attendance 24.

Kv-A. Meters, by Ira Knox, student. February 24. Attendance 16.

Business Meeting. March 3. Attendance 23.

Opportunities of the Engineer Outside of the Big Corporations, by Professor Hill. A motion picture, entitled "Letting Dynamite Do It," was also shown. March 10. Attendance 24.

University of Arizona

The Development of Electrical Production, by Professor Paul Cloke. February 6. Attendance 21.

Motion picture, entitled "The Westinghouse Institution," was shown. February 13. Attendance 19.

Improvement in Laundry Operation, by E. Brooks; *The Mercury Type Wattour Meter*, by W. R. Brownlee; and *The Westinghouse Student Course*, by W. Butler. February 20. Attendance 20.

Proceedings of Society for Advancement of Science, by Professor Paul Cloke; *The New Gas-Electric Truck*, by J. A. Denzer; and *Photographing the Interior of a Rifle Barrel*, by J. W. Cruse. February 27. A motion picture, entitled "A Telephone Call," was also shown. February 27.

University of Arkansas

Motion Pictures, entitled "The Audion" and "Speeding Up on Deep Sea Cables," were shown. February 16. Attendance 32.

Henry Ford's Life and the Ford Industry, by C. W. Collier; and *Need of Increased Efficiency in Use of Coal*, by Gilbert Cecil. March 2. Attendance 19.

Brooklyn Polytechnic Institute

The Operation of the Dial System, by E. H. Goldsmith, New York Telephone Co. February 17. Attendance 42.

University of California

Social Meeting. February 18. Attendance 90.

Carnegie Institute of Technology

The Outlook of the Electrical Industry, by W. E. Caven, student; and *Radio Reception*, by J. R. Balsley, Westinghouse Electric & Mfg. Co. January 20. Attendance 55.

Smoker. February 12. Attendance 100.

Side-Bands in Transatlantic Radio Telephony, by R. F. Riegelmeier, student; and *Conditions Which a Graduate Engineer Must Face after Graduation*, by Fred Coggswell, Pittsburgh Railways Company. March 3. Attendance 23.

Catholic University of America

Motion pictures, entitled "History of the Telephone" and "The Making of a Telephone Desk Set," were shown. February 16. Attendance 20.

University of Colorado

Recent Developments in the Art of Communication, by M. B. Long, Bell Telephone Laboratories. February 15. Attendance 150.

The Possibilities of the Engineering Graduate in Industry, by R. F. Carey, Westinghouse Electric & Mfg. Co. February 16. Attendance 60.

Motion Pictures, showing the plants of the Westinghouse Electric & Mfg. Co., were shown. February 17. Attendance 70.

The Oscillograph, by L. E. Swedlund; *Automatic Substations*, by O. V. Miller; and *High-Voltage Insulators*, by P. M. Brown. March 3. Attendance 110.

University of Denver

High-Temperature Insulation, by Bruce MacCannon. Illustrated with slides. February 3. Attendance 11.

Motion picture, entitled "Temperature and Motor Endurance,' was shown. March 2. Attendance 43.

Drexel Institute

Automatic Motor Control, by F. R. Fishback, Electric Controller and Mfg. Co. February 19. Attendance 50.

University of Florida

The Electrification of Railroads in Chile, by L. S. Boggs, Westinghouse International Co. February 22. Attendance 20.

The Utilization of the Peat Bog of Florida, by Robert Ranson. March 8. Attendance 22.

Georgia School of Technology

A motion picture, entitled "Okonite," was shown. March 2. Attendance 35.

Iowa State College

The Bell System from the Standpoint of an Engineering Student, by L. S. Lambert, Northwestern Bell Telephone Co. March 3. Attendance 95.

Power Station Operation, by J. M. Drabelle, Iowa Railway and Light Co. March 10. Attendance 73.

State University of Iowa

Opportunities at the Bell Telephone Co., by C. W. Davis; and *Listen to Your Speaker*, by J. R. Eyre. February 17. Attendance 43.

Mercury-Vapor Steam Cycle, by W. E. Evitts. February 24. Attendance 38.

Lightning, by K. C. DeWalt; *The Oil-Electric Locomotive*, by S. L. Eppel; and *Engineering-Report Writing*, by E. P. Farrel. March 3. Attendance 42.

Lafayette College

Modern Telephony, by C. L. Craven and P. O. Farnham, students. Illustrated with slides and motion pictures. February 24. Attendance 21.

Lewis Institute

Business Meeting. March 4. Attendance 15.

Marquette University

Railway Signalling, by H. F. Dennett and U. G. Carneiro, students. January 14. Attendance 28.

The Design of Induction Motors, and Their Application, by Frazier Heffrey, Allis-Chalmers Mfg. Co. Illustrated with slides. February 4. Attendance 26.

Massachusetts Institute of Technology

Inspection trip to Edgar Station, at Weymouth, of the Edison Electric and Illuminating Company. March 1. Attendance 31.

University of Michigan

A motion picture, entitled "The Rochester Gas, Electric Light and Power Company," was shown. February 26. Attendance 50.

School of Engineering of Milwaukee

America in the Balances, by James Quarles. A motion picture, entitled "Beyond the Microscope," was also shown. February 23. Attendance 32.

A motion picture, entitled "Wizardry of Wireless," was shown. March 9. Attendance 35.

Missouri School of Mines and Metallurgy

Motion pictures, entitled "Transportation" and "Waterpower," were shown. March 10. Attendance 42.

Montana State College

Carrier Telephony on High-Voltage Power Lines, by W. V. Wolfe, Bell Telephone Laboratories, Inc. February 15. Attendance 161.

Electric Power and Light Utility, by Thomas Heal. February 22. Attendance 154.

University of Nevada

My Experiences in Mexico, by Mr. Johnston. A motion picture, showing college life at the University of Nevada in the year 1914, was shown. February 24. Attendance 40.

College of the City of New York

Business Meeting. The following officers were elected: Chairman, James Wilson; Vice-Chairman, Frank Kulman; Secretary, Joseph Leipziger; Treasurer, E. F. Day; Publicity Manager, Jacob Herson. February 11. Attendance 23.

The Manufacture of Weston Instruments, by Mr. Corby, Weston Electrical Instrument Corp. Illustrated with slides. March 4. Attendance 36.

University of North Carolina

Business and Social Meeting. The following officers were elected: President, M. L. Murchison; Vice-President, G. M. Wilson; Secretary, D. M. Holshouser; Treasurer, F. A. Urbston. February 11. Attendance 34.

University of North Dakota

Life and Work of Oliver Heaviside, by Norman Bue, student. March 8. Attendance 19.

Northeastern University

Some Problems of a Public Utility Company, by L. L. Elden, Edison Electric Illuminating Co. February 15. Attendance 215.

Resistance and Impedance Amplification, by Professor R. G. Porter. February 26. Attendance 42.

Ohio State University

Mr. Allen Smith, Columbus Railway Power and Light Co., gave a talk on his experiences since his graduation in 1923. February 12. Attendance 80.

Oklahoma Agricultural and Mechanical College

A motion picture, entitled "Queen of the Waves," was shown. January 27. Attendance 87.

Pennsylvania State College

Salary Statistics of Alumni, by W. B. Watkeys; *A Study of Engineering Graduates*, by E. R. Queer; and *Adverse Comments on Engineering Prospects*, by John Doe. February 24. Attendance 35.

Purdue University

Distribution Transformers, Their Design, Development and Selection, by E. A. Wagner, General Electric Co. Illustrated with slides. February 25. Attendance 425.

Synchronous Apparatus, by W. T. Berkshire, General Electric Co. Illustrated with slides. March 9. Attendance 50.

Rensselaer Polytechnic Institute

Industrial Control Problems, by H. L. Perdiue, General Electric Co. Illustrated with slides. February 23. Attendance 150.

Rhode Island State College

Flux Linkage vs. Flux Cutting, by Mr. Laycock and Mr. Harvey. January 22. Attendance 16.

Business Meeting. February 5. Attendance 17.

Rose Polytechnic Institute

Motor Applications, by H. W. Rogers, General Electric Co. Illustrated with slides. March 4. Attendance 52.

Rutgers University

Radio Control of Transformers, by Arthur Palme, General Electric Co. February 8. Attendance 25.

University of South Dakota

Outstanding Developments in the Electrical Industries, by Stverak; and

Developments in High-Voltage Power Transmission, by Mr. Brackett. January 12. Attendance 10.

Developments in Switchboard and Portable Instruments, by Mr. Doohen. Illustrated with slides and motion pictures. February 12. Attendance 71.

University of Southern California

Business Meeting. January 14. Attendance 25.

Business Meeting. The following officers were elected: Chairman, J. H. Shideler; Vice-Chairman, B. L. Iris; Secretary, E. E. Smith; Treasurer, Willard Bausman. January 21. Attendance 27.

Syracuse University

Theoretical Aspects of Conduction in Vacuo and in Gases, by Leroy Mickey. February 15. Attendance 19.

Practical Aspects of Conduction in Vacuo and in Gases, by E. J. Stanmyre. February 22. Attendance 19.

Texas Agricultural and Mechanical College

Induction, by C. M. Thorne, student, February 19. Attendance 65.

University of Texas

Business Meeting. February 11. Attendance 16.

The Midwinter Convention of the A. I. E. E., by Professor J. M. Bryant. February 25. Attendance 20.

Virginia Polytechnic Institute

The Electron Theory, by F. L. Robeson. March 3. Attendance 41.

State College of Washington

Business Meeting. The following officers were elected: President, E. L. Clark; Vice-President, Stanley Bobel; Secretary, Harry Meahl; Treasurer, Mr. Beattie. January 28. Attendance 18.

Washington University

The New KMOX Broadcasting Station, by Mr. McNammie, Kennedy Radio Co. February 4. Attendance 26.

University of Washington

Obstacles Encountered by the Engineer in the Business World, by Glen Smith. February 3. Attendance 25.

The Telephone System, by F. D. Carroll, Pacific Bell Telephone Co. March 4. Attendance 13.

West Virginia University

Inside-Frosted Lamps, by W. F. Davis; *Porcelain Insulators*, by E. H. Braid; *An Epoch-Making Engineering Achievement*, by H. S. Muller; *Electrical Research as Applied to the Phonograph*, by J. W. Schramm; *Hydro-Electric Project in the Tennessee Valley*, by W. A. Williams; *Electric Elevators in Practise*, by K. D. Stewart; *Advantages of Highway Lighting*, by L. S. Davis; *Electric Elevators*, by P. S. Shobe; *A-C. Effects on Telephones*, by G. E. Meintel; *Measuring Sag*, by D. E. Akins; *Dangers Due to Over-Motoring*, by J. Criechi; *World War Radio*, by A. M. Kalo; *Over-Motoring*, by W. L. Nuhfer; and *Electric-Elevator Practise*, by I. L.Smith. February 19. Attendance 30.

Electric Railways, by R. W. Beardslee; *Engineers at Camp Custer*, by J. U. Neill; *Electrification of N. & W. Railroad*, by E. A. Berry; *Concrete Lighting Poles*, by C. M. Borror; *Recent Oscillograph Developments*, by G. H. Cornell; *Resistance of Electrical Connections*, by *G.* R. Latham; *Under-Sea Telephones*, by H. S. McGowan; *New Brushholder*, by A. L. Schneichal; *Tennessee Power Project*, by C. B. Binns; *Two-Winding Motors*, by *W. W. Reed*; *Photo-Electric Cell*, by J. L. Kessinger; *Radiodynamics*, by B. R. Shafer; *Standardization of Electron Tubes*, by W. E. Vellines; and *Electrification of N. Y., N. H., and Hartford Railroad* by R. L. Cole. February 26. Attendance 35.

Electric Transmission for Internal-Combustion Engines, by W. F. Davis; *Mica Insulation*, by E. H. Braid; *Use of Resin in Paper Making*, by H. S. Muller; *Electric Furnaces*, by J. W. Schramm; *How Edison Won the War*, by K. D. Stewart; *Electric Furnace Applications*, by D. E. Akins; *Electrolyzing Glass*, by E. R. Long; *Automatic Office-Building Sub-Stations*, by A. M. Kalo; and *Soldering Aluminum*, by W. L. Nuhfer. March 5. Attendance 28.

Micarta Products, by C. M. Barror; *High-Frequency Currents*, by G. H. Cornell; *Unattended Lighthouses*, by G. R. Latham; *Induction Brass Furnace*, by H. S. McGowan; *Renewing Bearings for Railway Motors*, by A. L. Schmeichel; *Cables on Bear Mountain Bridge*, by C. B. Binns; *High-Torque Synchronous Motors*, by W. W. Reed; *Experiences on the Road*, by L. S. Davis; and *Telephoning Beneath the Sea*, by B. R. Shafer. March 12. Attendance 24.

University of Wisconsin

Electrochemistry—a Factor in Electrical Engineering, by Professor L. Kahlenberg. February 23. Attendance 27.

University of Wyoming

Accident Prevention, by Corlis Van Horne. February 25. Attendance 11.

Yale University

Opportunities in Radio for the Electrical Engineer, by O. E. Dunlap, Radio Editor, *New York Times*. March 9. Attendance 39.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

DESIGNER, technical graduate, who has had at least two or three years' experience, in design in all kind of transformers of less than 5 K. W. Location, Massachusetts. R-8682.

ELECTRICAL ENGINEER, young, technical graduate, with 2-2½ years' experience, preferably with cable company. Work will be testing and research on cables. Apply by letter. Salary up to $48 a week. Location, New York. R-8851.

SALES ENGINEER, electrical, not over 42, to take charge of syndicate sales. Salary $7500 a year. Apply only by letter. Headquarters, New York City. R-9040.

SALES ENGINEER, to sell heavy machinery to public utilities. Must know public utility trade. Apply only by letter. Salary $6000 a year. Headquarters, New York City. R-9042.

ELECTRICAL SWITCH DESIGNER, for automatic control of direct and alternating current motors. Opportunity. Apply by letter stating technical training, experience, age and required salary. Location, New York City. R-9039.

DRAFTSMEN, under 40, with technical education and several years' experience. Resident of West Philadelphia preferred. Permanent. Opportunity. Apply by letter. Location, Pennsylvania. R-8605.

GRADUATE ELECTRICAL ENGINEER, as technical assistant to engineer in charge of meter work in public utility. Opportunity. Apply by letter with complete details of age, education, training, experience and salary desired with recent photograph. Location, New York City. R-9229.

MEN AVAILABLE

ELECTRICAL ENGINEER, seven years' experience in distribution engineering with two large power companies, desires position with a moderate sized public utility company or industrial concern in the Middlewest. C-964.

SALES ENGINEER, age 26, married, graduate M. I. T., one year construction, three years apparatus design, desires position with a growing concern where a thorough technical knowledge combined with design ability will assist in increasing sales, servicing products, and opening new fields. Employed. Available in one month. Location Anywhere. Minimum $3000. C-307.

CORNELL GRADUATE, E. E. '20, age 27, fourteen months Westinghouse shop and student course, twenty-two months substation operation, nine months test, and twenty-two months general engineering with large public utilities. At present employed. Desires permanent connection with opportunity for advancement. B-4484.

ELECTRICAL ENGINEER, age 32, single, technical graduate, one and one-half years G. E. test, and four years' marine experience. At present chief engineer on Coast Guard destroyer. Desires permanent employment in electrical engineering field with good opportunity for advancement. Available on reasonable notice. Location immaterial. C-396.

ELECTRICAL ENGINEER, age 28, married, eighteen months G. E. Company, six years design, construction and maintenance with electric utilities. Now employed on automatic substation design. Desires permanent connection with utility in Middlewest. Available on thirty days' notice. C-326-308.

SUPERINTENDENT OF ELECTRIC CONSTRUCTION, age 34, married, thoroughly competent to take complete charge of large installations. Six years' actual experience on commercial buildings, city schools, power house and signal stations. Would also consider plant maintenance. Master license. Available immediately. Location, N. Y. B-9638.

PRACTICAL MANUFACTURER AND ENGINEER, married, age 38. Has controlled manufacture and distribution of $250,000,000 of products in eight plants, all of which he reorganized, improved, financed, and managed with resultant increased earnings. He is among the nationally known younger executives. Available within reasonable time. If you desire increased production, distribution, and earnings, write C-699.

ELECTRICAL ENGINEER, age 29, married, graduate Ohio State University in electrical engineering, one and one-half years work in Commerce College, majored in economics and accounting. Experience; two years electrical contracting, and two years sales and production analysis in manufacturing corporation. Available within three weeks' notice. Prefers Ohio or vicinity. B-9865.

ELECTRICAL ENGINEER, age 27, single, speaks, reads and writes fluently English, Spanish and German. Five years' experience in technical, sales and instruction work. Prefers public utility company, or large mining, or metallurigal concern. Location, Mexico or Latin America, preferably Mexico. Salary desired $3000 U. S. currency. C-1027.

RADIO ENGINEER of Spielman Electric Corporation, age 22, single. In radio manufacturing business for himself from 1923-26. Executive ability, and production manager, and designer of sets. Available on two weeks' notice. Location, New York City. C-1020.

ELECTRICAL ENGINEER OR SUPERINTENDENT, age 34, married, eleven years' experience power plant construction, operation and maintenance of same on steam and hydro, including electric railway, substations, power distribution, transmission. Broad experience on industrial electrifications. Can make estimates and layout work. Desires connection with power or engineering company. C-761.

ADVERTISER having twenty years design and construction of power plants, etc., will proceed Pacific Coast permanently this Fall, and desires connection as sales engineer, representative or similar for engineering equipment, electrical or mechanical. Four years with manufacturer's agent abroad handling wide variety engineering apparatus, part of time manager branch office. 41, married, now in New York. B-7371.

PLANT ENGINEER OR MASTER MECHANIC, 39, experienced United States and British steam, gas, hydraulic, electric power plant construction and operation, also industrial and building maintenance. Now employed Middle Northwest, desires good industrial connection. $4000 minimum. Specialty, revamping, harmonizing and maintaining plants up to 5000 K. W. C-987.

ELECTRICAL ENGINEER, 32, college graduate, desires position on general electrical construction, or outdoor substation design. Has had four years of construction, repair and operating experience, three years of drafting and design experience on outdoor substations. Available on two weeks' notice. C-991.

ELECTRICAL ENGINEER, age 31, married, experienced in design, layout, and supervision of construction on indoor and outdoor substations and industrial installations. Location, South America, or Southwest United States. Available fifteen days' notice to present employer. C-1002.

ASSISTANT PROFESSOR OF ELECTRICAL ENGINEERING in strong state university, desires position with progressive, growing educational institution. 34, health excellent, married, eleven years' teaching experience covering all basic and many specialized electrical engineering courses, both theory and laboratory. Experience construction, maintenance with small public utility. Opportunity to do graduate work desirable, but not essential. Available in September. C-1040.

GRADUATE ENGINEER, desires position as chief engineer with concern manufacturing small electrical apparatus, such as motor driven appliances, and also heating devices. Has had experience in design and development, as well as in manufacturing. Age 39. Now employed. A-4660.

MANUFACTURERS' REPRESENTATIVE located in Sydney, N. S. W., Australia, desires additional agencies for American products of electrical and mechanical nature. Technical training, experience, knowledge of conditions. C-798.

ELECTRICAL ENGINEER, graduate Polytechnic Institute of Turin (Italy), 25, single, two years' experience in central station and substation work with the Brooklyn Edison Company. Thorough knowledge relay and protection problems. Desires position with public utility of manufacturing company. Location, vicinity New York. Available on one week's notice. B-8751.

ELECTRICAL ENGINEER, age 44, technical graduate, desires an executive position with public utility, or managment company located in New York City. Last eight years supervised electrical design construction and operation of large mining company in South America. Successful in handling men and interested in personnel work. Available at once. C-1074.

MEMBER A. I. E. E. having connections with important electrical and mechanical concerns abroad for representation in United States, wishes to connect with New York concern to utilize his ability and business relations. B-8609.

INSTRUCTOR ELECTRICAL ENGINEERING, desires for coming (1926-27) collegiate year a change, with promotion to assistant or associate professorship in Eastern or Midwestern university. Man with initiative; ability as teacher. At present teaching the more advanced subjects. Has outgrown present position which can offer no promotion. M. S., B. S. degrees. age 30, married. Eight years' professional and teaching experience. B-3376.

ELECTRICAL ENGINEER, age 27, energetic, inventive and tactful. Past experience, electrical testing and charge of electrical testing apparatus and research. Good references. Desires position developing and research of electrical apparatus or machinery. At present employed, but available on two weeks' notice. Greater New York preferred. B-7270.

INDUSTRIAL ENGINEER, technical, mechanical, electrical engineer, with ten years' practical experience in factory operation, organization and management, wishes change in location. Present position, production manager of factory of twelve hundred employees, branch of one of world's largest corporations. Responsible and in charge of everything except accounting which comes under business manager. C-1070.

ELECTRICAL ENGINEER, age 28, single, wishes position as executive, or assistant electrical engineer. Good character, pleasing personality. German, English, French. Familiar theory and practice electrical and scientific measurements, electrical instruments, meters, relays. Transmission, distribution, protection, dielectric circuits. Three years research laboratory, two years designing. Location, preferably New York. Minimum salary $3500. Available on month's notice. C-930.

ELECTRICAL ENGINEER, age 24, technical graduate, thirteen months G. E. test, year and one-half on electric division of railroad, New York City. Shop experience, testing, inspection, maintenance, cars, locomotives, supervision of car construction, drafting, design. Desires position with power company, industrial, or engineering concern in New York or New England. C-1048.

GRADUATE ELECTRICAL ENGINEER, age 30, with commercial sense, excellent technical training, practical and commercial experience. Familiar with best up to date practice in industrial and central station electrical practice. Available immediately for industrial, or central station engineering management position. Location, North Central States. C-1071.

ELECTRICAL ENGINEERING GRADUATE, with special ability in writing, and the preparation of technical literature, desires position with a manufacturer or distributor of radio equipment, in sales or publicity work. Radio experience before attending college. Available upon graduation in June. Married, 24. Prefers Pacific Coast. C-1067.

CORNELL GRADUATE, with twenty years' experience in design, construction, operation and management of hydro and steam power systems. Now employed, desires change, preferably in New York, San Francisco, or foreign position. Four years in Latin America. Capable of managing entire property, including finances. 39, married. A-3494.

E. E. AND M. E. Graduate, married, six months telephone switchboard installer for Western Electric, one year G. E. test course, one year with a large public utility in the switchboard and substation engineering department, wishes position with future. C-1068.

HIGH GRADE EXECUTIVE AVAILABLE, sixteen years' experience in large and moderate sized electrical and mechanical manufacturing plants in East and Middlewest covering production, equipment, product design, sales and industrial engineering. Engineering education, age 37, married. Employed as departmental manager, but wishes to broaden opportunities. C-1050.

ENGINEER, with twenty years' hydro and steam power plant experience; last ten years in management, four years in Latin America. Cornell training. Now employed. Prefers New York, San Francisco, or foreign position. A-3494.

DEVELOPMENT OR PRODUCTION ENGINEER, age 37, married, graduate M. I. T. electrical engineering. Experience covers manufacture small electrical apparatus, trouble shooting on assemblies, specification writing, technical correspondence, laboratory work organizing manufacture of delicate A. C. measuring apparatus. Have canvassed for sales. Can be of service on development of electrical specialties, or on production working between development engineers and factory. Available at once. Location, New York City. C-1018.

ELECTRICAL ENGINEER, age 28, single, technical graduate, desires position with manufacturer electrical apparatus. Five years' experience with engineering department of large company manufacturing industrial control equipment. A little sales experience. Minimum salary $2500. Available on reasonable notice. B-6274.

ELECTRICAL ENGINEERING GRADUATE, age 30, now student at a prominent university, accurate with mathematical calculations, desires summer work with engineering firm in New York. Can do drafting, but prefers engineering calculations. Available about July 1st. to September 30th. B-7526.

ENGINEER, 27, married, Stanford graduate, 1920, mechanical engineering. One year managing engineer gas and fuel company, five years engineering department, desires business end of engineering position. Can make investment. Available at once. Location, California. C-1057-2-C-10.

PRACTICAL ELECTRICAL AND TELEPHONE SUPERINTENDENT, age 38, construction, reconstruction, operation or maintenance; nine years Latin America. Returning to States on account of schooling for children. References. C-1088.

WORKS MANAGER-EXECUTIVE ENGINEER, post graduate electrical engineer, age 43, twenty years engineering, shop management, sales; development engineer, Westinghouse, six years, manager five years manufacturing department large electrical company. Traveled abroad, negotiating important contracts. Now executive engineer, assisting sales reorganization old established concern. Consider only managing position. Would go abroad. Salary $7500. C-30.

TECHNICAL GRADUATE IN ELECTRICAL ENGINEERING, age 32, married, desires a position with a public utility having an underground cable system. Very familiar with cable failure locating devices, U. G. operating problems, electrolysis surveys. Absolutely reliable and hard worker. Willing to go anywhere. Available anytime with reasonable amount of notice to present employers. C-1093.

MECHANICAL-ELECTRICAL ENGINEER, age 30, mechanical engineering graduate 1916, two years of plant equipment supervision, three years of research and design in radio for Navy Department, three years as assistant to consulting engineer with general practice. Has spent eighteen years actively in radio field. Desires position giving sales training, no objection to traveling. Minimum salary $3000. Available after notice of one month. C-2003.

1925 GRADUATE ELECTRICAL ENGINEER, Georgia Tech, Age 24, sales and business experience, desires position with possibilities for advancement with public utility, or electrical contracting company. Location, preferably Florida or Georgia. C-2004.

ENGLISH CONSTRUCTION ENGINEER, age 38, with wide factory and power station experience, desires responsible position abroad. Accustomed to tropical climates and handling of native labor. C-1092.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED MARCH 16, 1926

AAROE, ERLING, Designer, Electric Bond & Share Co., 71 Broadway, New York; res., Brooklyn, N. Y.

ALGER, CLERE SEWELL, Meter Tester, Puget Sound Power & Light Co., Seattle, Wash.

ALLSCHWAGER, ORA R., Statistical Clerk, Northern States Power Co., 15 S. 5th St., Minneapolis, Minn.

ANDERSON, DEXTER PERRY, Telephone Switchboard Equipment Engineer, Western Electric Co., Chicago, Ill.

*ANDERSON, WILLIAM BENTON, Design Engineer, Power Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

APPS, WALTER G., Student, School of Engg., Milwaukee, Wis.

BASURTO, RICARDO, Inspector, Control Electrotecnico de Mexico, Secretaria de Industria y Comercio, Capuchinas No. 30, Mexico D. F.; res., Tacuba, D. F., Mex.

BAUER, CONRAD ARTHUR, Electrical Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BAUERSCHMIDT, GERALD JOHN, Electrical Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BAUM, SYDNEY H., Technical Dept., Chas. Freshman Co., 240 W. 40th St., New York; res., Brooklyn, N. Y.

BENYO, GEORGE, Draftsman, New York Edison Co., Irving Place & 15th St., New York; res., Brooklyn, N. Y.

BERK, HENRY H., Meter Tester, Puget Sound Power & Light Co., 7th & Olive, Seattle, Wash.

*BEST, ALBERT O., Ignition & Repair Service Station, 21401 Sherman Way, Owensmouth, Calif.

*BIOSCA, LOUIS F., Radio Research Engineer, Federal Radio Corp., 1738 Elmwood Ave., Buffalo, N. Y.

BLACK, WILLIAM LINDSAY, Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Nutley, N. J.

BLANDING, WILLIAM P. T., Substation Operator, Bureau of Power & Light of Los Angeles, 207 S. Broadway, Los Angeles, Calif.

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BOYCE, WILLIAM HOWARD, Designing Engineer, Delta Star Electric Co., 2433 Fulton St., Chicago, Ill.

BOYER, QUINN ODELL, Draftsman, Inside Plant, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

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BROWN, GEORGE ROMAINE, Chief of Electrical Laboratory, Western Electric Co., Hawthorne Sta., Chicago, Ill.

*BRUGGER, KARL ANTHONY, Ass't. Construction Engineer, Public Utility Co., East Dubuque, Ill.

BUDDEN, ARTHUR NAPIER, Engineer, General Electric, S. A., Mexico D. F., Mexico.

BUELL, ROY C., Engineer, General Electric Co., Schenectady, N. Y.

BUNCE, LEWIS I., Supt., The Belamose Corp., Rocky Hill, Conn.

BUTTON, FRANK E., Hudson View Gardens, West 180th St. & Pinehurst Ave., New York, N. Y.

CADAVERO, ALFRED, Electrical Tester, New York Telephone Co., 547 Clinton Ave., Brooklyn; res., New York, N. Y.

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CRUMLEY, HOWARD LEE, Protection Engineer, Georgia Railway & Power Co., Atlanta, Ga.

CUMMINGS, EDWARD BARTLETT, System Operator's Office, United Hudson Electric Corp., New Paltz, N. Y.

DANN, THOMAS WALTER, Asst. Engineer, Switchgear & Development Dept., General Electric Co., Witton, Birmingham, Eng.

*DATTA, RAJINDRA SINGH, Elec. Engg. Dept., Bucyrus Co., South Milwaukee, Wis.

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McGEE, JESSE SCOTT, Dist. Supt., Monongahela West Penn Public Service Co., Grafton, W. Va.
McGOWAN, LEON F., Drafting, Rochester Gas & Elec. Co., Rochester, N. Y.
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*MILLER, RALPH F., Graduate Student, Educational Dept.; Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Reading, Pa.
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NELSON, NELS, Assistant Electrical Engineer, Adirondack Power & Light Corp., Clinton St., Schenectady, N. Y.
NIGHTINGALE, RICHARD, Electrical Engineer, Light Dept., City of Tacoma, City Hall, Tacoma, Wash.
NOERR, ALBERT EDWARD, Electrical Engineer, Noerr Electric Service, Suva, Fiji Islands.
OAKE, CYRIL JOSEPH, Deputy Electrical Engineer & Manager, British Municipal Council, Tientsin, N. China.
OLDS, CLARENCE DUDLEIGH, Distribution Engineer, Puget Sound Power & Light Co., 301 E. Holly, Bellingham, Wash.
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PETTET, CECIL CHARLES, Inspection Engineer, Northern Electric Co., Ltd., 131 Sherer St., Montreal, P. Q., Can.
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PRICE, ARTHUR VALLEAU, Florida Power & Light Co., Daytona Beach, Fla.
*PRUDHOMME, DONALD JAMES, Student, Oregon State College, 320 N. 9th St., Corvallis, Ore.
PUTNAM, RUSSELL CALDWELL, Instructor, Dept. of Elec. Engg., Case School of Applied Science, Cleveland, Ohio.
RANKIN, HARRY CURTIS, General Tester, The New York Edison Co., 708 1st Ave., New York, N. Y.
REILLY, FRANK WILLIAM, Asst. Electrical Engineer, Carleton-Mace Engineering Corp., 10 High St., Boston; res., Atlantic, Mass.
REIMEL, SAMUEL ROY, Asst. Test Engineer, B. F. Goodrich Co., Akron, Ohio.
*RICE, JANVIER MAYHEW, Instructor, Dept. of Mathematics, Pennsylvania State College, State College, Pa.
*RICHARDS, F. IRA, Student Engineer, General Electric Co., Schenectady, N. Y.
RIEMAN, HARRY MARTIN, Distribution Div., Engg. Dept., Central Hudson Gas & Electric Co., 50 Market St., Poughkeepsie, N. Y.
RODEWIG, LOUIS FREDERICK, Estimator, General Electric Co., 120 Broadway, New York, N. Y.
ROGER, WILLIAM HUGH GREGORY, Electrical Drafting c/o Fraser, Frew & Dryer, Ltd., 448 Seymour St., Vancouver, B. C., Can.
ROSE, DONALD L., Station Electrician, Southern California Edison Co., Power House No. 3, Big Creek, Calif.
ROWLEY, CLYDE, Substation Operator, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
*RUPPELL, EDWARD AUGUST, Manager, Grand Central Electric Corp., 247 Park Ave., New York; res., Hart Park, N. Y.
SAFDAR, H., Power Controller, G. I. P. Railway, Matunga, Bombay, India.
SASSEN, CHARLES H., Supt. Elec. Maintenance & Construction, Hudson Coal Co., Scranton, Pa.
SCHAEFER, PHILIP EMIL, Job Supervisor, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
*SCHROEDER, HENRY WILLIAM, Tester, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.
SCHULTZ, HERBERT GORDON, Supervisor, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
SCOTT, CARL, Electrical Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
SEDERBERG, NORMAN W., Generating Station Operator, Brooklyn Edison Co., Gold St. Generating Station, Brooklyn; res., New York, N. Y.
SEELYE, ALBERT F., Chief Electrician, Boise Payette Lumber Co., Barber, Idaho.
SHARPSTEEN, JOHN LUCIUS, Draftsman, Pacific Gas & Electric Co., 447 Sutter St. San Francisco; res., Alameda, Calif.
SHULZE, GEORGE FRANKLIN, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Maplewood, N. J.
*SHUMAN, URIAH SIDNEY, Asst. Supt. of Distribution, Philadelphia Suburban Gas & Electric Co., Newtown, Pa.
SIBLEY, WILLIAM CHARLES, Chief Operator, Substation, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
SISLER, FRANK G., Final Tester, The Electric Controller & Mfg. Co., 2700 E. 79th St., Cleveland, Ohio.
SMITH, ARNE CHRISTOPHER, Electrical Engineer, Development & Test Dept., Otis Elevator Co., 1 Woodworth Ave., Yonkers, N. Y.
SMITH, CHARLES LAURENCE, Foreman Electrician, C. H. E. Williams & Co., Ltd., Vancouver, B. C., Can.
SMITH, H. WYLIE, Testing Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
SMITH, JOE L., Cable Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
SMITH, OLIVER, Electrical Draftsman, Thomas E. Murray, Inc., 55 Duane St., New York; res., Corona, N. Y.
*SMITH, VICTOR GEORGE, Research Assistant, University of Toronto, Toronto, Ont., Can.
SMITH, WILLIAM J., Inst., Calibrator, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.
*STAHL, CHOUTEAU PLATT, Student Engineer, General Electric Co., Schenectady, N. Y.
STARR, ARNOLD L., Sales Engineer, Clapp & LaMores, 310 E. 4th St., Los Angeles, Calif.

STOCK, ROBERT JOHN, Supervisor, Electrical Equipment, 604 Gwynne Bldg., Cincinnati, Ohio.
*STORY, THEODORE HARVEY, Acting Supt. of Construction, Turner Construction Co., 244 Madison Ave., New York; res., Brooklyn, N. Y.
STOVER, JAMES R., Electrical Designing Engineer, Metropolitan Edison Co., 16 S. Fifth St., Reading, Pa.
*STOVER, MERRILL McCORD, General Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.; res., Elmhurst, N. Y.
STOWERS, LOUIS G., Equipment Engineer, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
SUDLER, EDWARD O., Instructor, Bliss Electrical School, Takoma Park; res., Washington, D. C.
SYKES, PAUL MISCHLER, 1510 S. Center St., Terre Haute, Ind.
TAGGART, CHARLES W., General Manager, City of Norwich Gas & Elec. Dept., 34 Shelucket St., Norwich, Conn.
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TAYLOR, FLOYD F., Power Plant Operator, Salt River Valley Water Users Association, Lake Side Club, Roosevelt, Ariz.
TEAGUE, JOHN A., Chief Electrician, Baker Iron Works, 950 N. Broadway, Los Angeles, Calif.
THOMAS, CECIL HUBERT, Technical Assistant, Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.
*THOMPSON, ALBERT CLARK, Engineer, Dept. of Dev. & Research, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
THOMPSON, GEORGE SILAS, Chief Electrician, Fuel Dept.; Supt., New Power Plant, Colorado Fuel & Iron Co., Pueblo, Colo.
*THOMPSON, HARRY E., Inspector, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.
THOMSON, THOMAS B., Supt., Maintenance Dept., U. S. E. M. Co., 505 W. 42nd St., New York, N. Y.; res., Union City, N. J.
*THORSON, WILBUR RAYMOND, Distribution Engineer, Consumers Power Co., Kalamazoo, Mich.
*THURSTON, HOWARD ALLEN, Electrician, Columbus Railway, Power & Light Co., 209 N. Front St., Columbus, Ohio.
TIETZ, WILLIAM J., Methods Engineer, Western Electric Co., Hawthorne Station, Chicago, Ill.
TISDALE, WALTER H., Illuminating Engineer, Connecticut Power Co., Middletown, Conn.
TORGAN, NATHAN, Jr., Sales Engineer, Horni Signal Mfg. Corp., 153 Frelinghuysen Ave., Newark, N. J.; for mail, Providence, R. I.
TRIMBLE, LOREN, Operator, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
TRONE, EDWARD M., Electrical Engineer, Western Electric Co., Inc., Chicago; res., Brookfield, Ill.
TURNER, HAROLD ELLIOT, Central Station Engineer, General Electric Co., Schenectady, N. Y.
*VAN SICKLE, ROSWELL C., Design Engineer, Westinghouse Elec. & Mfg. Co., Wilkinsburg, Pa.
WALKER, FRANK VICTOR, Senior Operator, San Fernando Plant, Bureau of Power & Light City of Los Angeles, San Fernando, Calif.
WALLIS, CHARLES G., Industrial Control Design, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.
WALWORTH, STANLEY LINCOLN, Dist. Sales Representative, Pittsburgh Transformer Co., Columbus & Preble Aves., Pittsburgh, Pa.
*WEBER, HANARD P., Exciter Operator, Fisk St. Station, Commonwealth Edison Co., 22nd & Fisk Sts., Chicago, Ill.
WEST, GEORGE HARRISON, Station Electrician, Louisiana Electric Co., Inc., Lake Charles, La.
*WESTBROOK, JOHN LEWIS, Supt. Meter Dept., Compania Agricola 7 de Fuerza Electrica del Rio Conchos, S. A., C., Cia Agricola, C. Camargo, Chih., Mex.
WESTERMAN, A. G., Job Supervisor, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
WESTHOVEN, CASPER JOSEPH, Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
WHITAKER, EDWARD R., Electrical Foreman, Union Electric Light & Power Co., Ashley Sta., St. Louis, Mo.
WICK, RAYMOND JOSEPH, Tester, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.
WILBUR, DONALD ELDREDGE, Radio Operator, Pennsylvania Power & Light Co., Front St. Power House, Allentown; res., Bethlehem, Pa.
WILCOX, JOHN EDWIN, Chief Switchman, New York Telephone Co., 227 E. 30th St., New York; res., Brooklyn, N. Y.
WILLIAMS, ANEURIN TUDOR, Chief Operator, Hydro-Electric Power Station, Newfoundland Power & Paper Co., Ltd., Deer Lake, Newfoundland.
WILLIAMS, GURDON HUNTER, Road Engineer, Service Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
WILLIAMS, NIAL B., Chief Operator, Jefferson St. Power House, Puget Sound Power & Light Co., 423 7th Ave., Seattle, Wash.
*WINOGRAD, HAROLD, Electrical Engineer, American Brown Boveri Electric Corp., Camden, N. J.
WISHARD, WILLIAM W., Asst. Chief Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
WOLF, RICHARD, Jr., Student of Elec. Engg., Bahnhofstr 19, Mittweida, Sa., Germany.
*YOUNG, PAUL NATHAN, Technical Estimator, Detail & Record Bureau, Brooklyn Edison Co., Inc., 360 Pearl St., Brooklyn, N. Y.
*ZIMMER, FREDERIC M., Distribution Engineer, Ohio Power Co., 720 2nd St., S. E., Canton, O.

Total 280
*Formerly enrolled students

ASSOCIATES RE-ELECTED MARCH 19, 1926

ALTAMIRANO, SALVADOR E., General Manager, General Electric S. A., Mexico D. F., Mex.
DuBOIS, ALEXANDER DAWES, Engg. Dept., Electric Machinery Mfg. Co., 14th & Tyler St., N. E., Minneapolis, Minn.
MOLINA, F. JULIO, Electrical Engineer, Calle 59 No. 447, Merida, Yucatan, Mex.

MEMBERS ELECTED MARCH 19, 1926

ALLEN, LOUIS MICHAEL, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
BAXTER, NORMAN McLEOD, Engineer, The Ohio Public Service Co., Sandusky, Ohio.
CALL, CHARLES ARTHUR, Inspector, Ohio Insulator Co., Barberton, Ohio.
CRAMP, WILLIAM, Professor of Elec. Engg., University of Birmingham, Edgvaston, Birmingham, Eng.
HECHT, JULIUS L., Vice President, Public Service Co. of No. Ill., 72 W. Adams St., Chicago, Ill.
HORGAN, JAMES GALVIN, General Power Sales Engineer, Ohio Public Service Co., Cleveland, Ohio.
KNOST, JOHN HENRY, Jr., Engineer, Power & Industrial Dept., Westinghouse Elec. & Mfg. Co., 420 S. San Pedro St., Los Angeles, Calif.
KOPP, OTTMAR HUGO, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
ROUGHEN, RICHARD HARVEY, Supt., Sub-Sta. Dept., Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa.
VICKERS, HERBERT, Professor of Elec. Engg., Head of Dept. of Mech. Engg., University of British Columbia, Vancouver, B. C., Can.

TRANSFERRED TO GRADE OF FELLOW MARCH 19, 1926

COATES, WILLIAM A., Metropolitan Vickers Electrical Export Co., Tokyo, Japan.
DIXON, AMOS F., Systems Development Engineer, Bell Telephone Laboratories, New York, N. Y.
McIVER, GEORGE W., Jr., Asst. Manager, Electrical Dept., Toledo Edison Co., Toledo, O.
THOMS, ALEXANDER P., Asst. Supt., Street Department, Commonwealth Edison Co., Chicago, Ill.
WILLIAMS, SAMUEL B., Telephone Engineer, Bell Telephone Laboratories, New York, N.Y.

TRANSFERRED TO GRADE OF MEMBER MARCH 19, 1926

ADKERSON, BRANCH O., Inside Plant Engineering, American Tel. & Tel. Co., New York, N. Y.
AMBUHL, FRANK F., Asst. Chief Engineer, Toronto Hydro-Electric System, Toronto, Ont., Can.
ARCEO, ANTONIO, Supt. of Distribution, Mexican Light & Power Co., Ltd., Mexico City, Mex.
BANNISTER, ALBERT, Chief Assistant, Switch gear Sales Dept., Metropolitan Vickers Electrical Co., Ltd., Manchester, Englnd.
BELL, JOHN H., Telegraph Engineer, Bell Telephone Laboratories, New York, N. Y.
BOSTATER, HERBERT L., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.
DAVIS, URIAH, Load Dispatcher, Commonwealth Edison Co., Chicago, Ill.
EASTHAM, MELVILLE, President and Engineer, General Radio Co., Cambridge, Mass.
ENGLE, MELVIN D., Engineer, Station Engineering Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.
EVANS, ROBERT D., General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
FRIEND, HENRY M., Cable Engineer, Hugh L. Cooper & Co., New York, N. Y.
GARY, LAURENCE A., Engineer, Transmission Dept., Pacific Tel. & Tel. Co., San Francisco, Calif.
HASTINGS, MILTON B., Vice-President, Powerlite Devices, Ltd., Toronto, Ont., Can.
INNES, FRANK R., Asst. Editor, "*Electrical World*," New York, N. Y.
KERSEY, GLEN B., Field Engineer, Commonwealth Edison Co., Chicago, Ill.
McDOWELL, H. E., Electrical and Mechanical Engineer, Texas Power & Light Co., Dallas, Tex.
NASH, JOHN F., Electrical Engineer and Division Manager, Appalachian Power Co., Bluefield, W. Va.
RADER, RAY, Assistant Engineer, Puget Sound Power & Light Co., Seattle, Wash.
ROBERTS, SPENCER, Engineer, Day & Zimmerman, Philadelphia, Pa.
SCOFIELD, EDWARD H., Engineer of Power, Twin City Rapid Transit Co., Minneapolis, Minn.
SMITH, GEORGE S., Instructor of Electrical Engineering, University of Washington, Seattle, Wash.
STEVENS, THEODORE, Consulting Engineer, London, England.
VANHALANGER, L. J., Sales Engineer, Westinghouse Electric & Mfg. Co., Chicago, Ill.

WAY, HOWARD E., Special Agent, Electrical Equipment Div., Bureau of Foreign and Domestic Commerce, Washington, D. C.
WREAKS, HUGH T., Manager, Detroit Office, Boston Insulated Wire & Cable Co., Detroit, Mich.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held March 8, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

DWIGHT, HERBERT BRISTOL, Professor, Massachusetts Institute of Technology, Cambridge, Mass.
HEINZE, CARL A., Electrical Engineer in charge of Distribution, Department of Water & Power, City of Los Angeles, Los Angeles, Calif.
OEHLER, ALFRED G., Editor—Railway Electrical Engineer, Electrical Editor—*Railway Age*, New York, N. Y.

To Grade of Member

ANDERSON, EDWARD T., Electrical Engineer, Board of Water & Electric Light Commissioners, Lansing, Mich.
BACKUS, CYRUS D., Principal Examiner, U. S. Patent Office, Washington, D. C.
BOHNERT, ARTHUR M., District Engineer, Ohio Brass Co., San Francisco, Calif.
BOLLINGER, HOWARD M., Supervisor of Plant Methods, Chesapeake & Potomac Telephone Co., Washington, D. C.
Brockway, R. M., Engineer, Switchboard Dept., General Electric Co., Schenectady, N. Y.
CARPE, ALLEN, Engineer, Dept. of Development & Research, American Telephone & Telegraph Co., New York, N. Y.
CLAPP, ROBERT H., Telegraph Engineer, American Telephone & Telegraph Co., New York, N. Y.
COLBURN, WELLEN H., Electrical Engineer, Station Engineering Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.
CRESSEY, JOHN A., Control Engineer, South Wales Power Co., Upper-Boat Power Station, Treforest, Pontypridd, Glamorgan, England.
FINCH, WILLIAM G. H., Radio Editor and Engineer, International News Service, New York, N. Y.
GIBSON, E. S., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.
HEILBRUN, RICHARD Head of Firm, Dr. Richard Heilbrun, Manufacturer of Electric Appliances, Berlin, Germany.
JACKSON, DUGALD C., Jr., Asst. Professor of Electrical Engineering, Trinity College, Durham, N. C.
RAMIREZ, JAVIER P., Consulting Engineer, Professor—Escuela de Ingenieros Mecanicos Electricistas, Mexico City, Mex.
RORTY, M. C., President International Telephone Securities Corp.—Vice-President, International Tel. & Tel. Corp., New York, N.Y.
SAATHOFF, GEORGE W., Chief Construction Engineer, Henry L. Doherty & Co., New York, N. Y.
SPORN, PHILIP, Assistant to Electrical Engineer, American Gas & Electric Co., New York, N. Y.
SPRACKLEN, EMERY E., Electrical Engineer in charge of Design, Ohio Public Service Co., Massillon, Ohio.
TAYLOR, NEWTON S., Manager, Switchboard Section, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
WARFIELD, S. C., President & Engineer, M. O. & W. Engineering Corp., Morton, Va.
WHIPPLE, CLYDE C., Asst. Professor of Electrical Engineering, Polytechnic Institute, Brooklyn, N. Y.

APPLICATIONS FOR ELECTIONS

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before April 30, 1926.

Allen, T. D. N., U. S. Veterans' Bureau, Washington, D. C.
Allen, T. S., (Member), Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Andrews, S. W., Foundation Co , Pittston, Pa.
Ballew, R. E., Great Western Power Co., Oakland, Calif.
Banton, F. B., New Orleans Public Service Co., New Orleans, La.
Becker, F. A., Canadian General Co., Toronto, Ont., Can.
Beckett, W., (Member), Georgia Railway & Power Co., Atlanta, Ga.
Berting, G. A., The North Electric Mfg. Co., Galion, Ohio
Bettinger, L.W., U. S. S. Concord, c/o Postmaster, New York, N. Y.
Blenkarn, W. O., Salt Creek Electric Plant, Midwest, Wyoming
Beyrodt, K., Bond Service Repair Co., New York, N. Y.
Bodelsson, A. Pratt Institute, Brooklyn, N. Y.
Brown, H. H., Wisconsin Trac. Lt. Ht. & Pr. Co., Appleton, Wis.
Brown, R. E., Rhode Island State College, Kingston, R. I.
Burdin, A. J., Western Electric Co., Hawthorne Sta., Chicago, Ill.
Burkhardt, C. E., Municipal Power & Ice Plant, Sebastian, Fla.
Cady, W. M., Development Work, 108 Clinton Ave., Newark, N. J.
Carolan, W. A., 712 Putnam Ave., Brooklyn, N.Y.
Carpenter, H. W., Sangamo Electric Co., Boston, Mass.
Cates, R. V., American Tel. & Tel. Co., Charlotte, N. C.
Chant, A. E., Dept of Telephones, Regina, Sask., Can.
Clark, O. S., Union Gas & Electric Co., Cincinnati, Ohio
Clarke, P. C., General Electric Co., West Philadelphia, Pa.
Colvin, A. L., Lockport & Ontario Power Co., Angola, Ind.
Csepely, J. A., The Western Electric Co., Inc., New York, N. Y.
Crawford, W. K., Brooklyn Edison Co., Brooklyn, N. Y.
Davis, A. E. H., Frank J. Yorke Co., Detroit, Mich.
Davis, H. F., Monongahela West Penn. Public Service Co., Fairmont, West Va.
DeDona, A. J., Postal Telegraph Co., New York, N. Y.
de Zamacona, L., Mexican Light & Power Co., Mexico City , Mex.
Dreyfus, J., New York Tel. Co., Brooklyn, N. Y.
Duncanson, P., Western Electric Co., Kearny, N. J.
Dunstan, R. A., General Electric Co., Schenectady, N. Y.
Eighmy, G. W., General Electric Co.,Buffalo, N.Y.
Ellis, C. R., Louis T. Klauder, Philadelphia, Pa.
Elword, A., (Member), C. M. & S. Co., Ltd., Trail, B. C., Can.
Engelken, R. C., Brooklyn Edison Co., Brooklyn, N. Y.
Engh, J. S., Automatic Electric, Inc., Chicago, Ill.
Farrell, J. J., Great Western Power Co., Caribou Plumas Co., Calif.
Fleshiem, R. S., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
(Applicant for re-election)
Flory, A. C., (Member), Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Foltz, J. P., Westinghouse Elec. & Mfg. Co., Wilkinsburg, Pa.
Forkel, W. H., Metropolitan Electr. Manufacturing Co., Long Island City, N. Y.
Foster, H. B., Wireless Specialty Apparatus Co., Boston, Mass.
Fowler, J. R., Westchester Lighting Co., Mt. Vernon, N. Y.
Galer, F. C., Lancashire Dynamo & Motor Co., Toronto, Ont., Can.
Gigat, A. W., (Member), Granby Consolidated Mining, Smelting & Pr. Co., Anyox, B. C., Can.
Haddock, C. C., Brooklyn Edison Co., Brooklyn, N. Y.
Haig, C. M., New England Tel. & Tel. Co., Boston, Mass.
Hankey, W. J., The Cleveland Railway Co., Cleveland, Ohio
Harrington, G. W.,Pratt Institute, Brooklyn, N.Y.
Harrison, A. T.,Pacific Gas & Electric Co., Cassell, Calif.
Hepinstall, W. G., Lignite Utilization Board, Bienfait, Sask., Can.
Herrera, R. O., General Electric Co., Schenectady, N. Y.
Hindman, E. R., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Holton, T. R., 62 West Street Worcester, Mass.
Hudson, A., General Electric Co., Schenectady, N. Y.
Hudson, F. E., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hughes, G. O., Bureau of Pr. & Lt., City of Los Angeles, Saugus, Calif.
Ishii, T., Japanese Government Railways, New York, N. Y.
Jeannin, H. W., (Member), The Jeannin Electric Co., Toledo, Ohio
Jones, F. A. M., The Pacific Tel. & Tel. Co., San Franscisco, Calif.
Jones, J. P., Consulting Engineer, Cleveland, Ohio
Jund, D., with W. C. Lagerway, New York, N. Y.
Kelhofer, L. M., Commonwealth Power Corp., Jackson, Mich.
Khalifah, A. A., Baldwin Locomotive Works, Philadelphia, Pa.
Klein, F. A., Public Service Electric & Gas Co., Newark, N. J.
Kovalsky, J. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Kovediaeff, B. E., 1018 W. 73rd St., Los Angeles, Calif.
Kupferle, A. T., Union Gas & Electric Co., Cincinnati, Ohio
Lamantia, J. C., Brooklyn Polytechnic Institute, Brooklyn, N. Y.
Lappin, J. L., General Electric Co., Bloomfield, N. J.
Lauth, E. H., Street Lighting Sec., City of St. Louis, St. Louis, Mo.
Lewis, F. M., Northwestern Electric Co., Portland, Ore.
Mahood, E. T., Southwestern Bell Telephone Co., St. Louis, Mo.
(Applicant for re-election)
Manning, E. R., Weston Electrical Instrument Corp., New York, N. Y.
Markovits, J. A., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Marshall, A. E., The Philadelphia Electric Co., Philadelphia, Pa.
Martini, J. A., Postal Telegraph Co., New York, N. Y.
McGinnis, N. W., H. C. Reid & Co., San Francisco, Calif.
McGrath, M. H., Standard Underground Cable Co., Pittsburgh, Pa.
McIntyre, R. J., Gray Electric Chemical Laboratory, Bayonne, N. J.
McKeon, J. B., Rochester Gas & Electric Corp., Rochester, N. Y.
McLean, J. S., (Member), J. G. White Engineering Corp., New York, N. Y.
Mimmack, A., City Electrician, City Hall, Beverly Hills, Calif.

Mororo, D. G., 513 W. 145th St., New York, N. Y.
Morse, A. W., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Moss, J. E., West Penn Power Co., Washington, Pa.
Murphy, J. A., McClellan & Junkersfeld, Inc., St. Louis, Mo.
Nemetz, V. W., Commonwealth Power Corp., Jackson, Mich.
Nerges, F. A., U. S. S. Owl, No. 2, Hampton Roads, Va.
Overfield, G. B., Burke Electric Co., Erie, Pa.
Panton, H. A., Buffalo General Electric Co., Buffalo, N. Y.
Pasayiotis, G. N., Book-News & Novelty Co., Reading, Pa.
Petersen, H. N., Great Western Power Co. of California, Oakland, Calif.
Peterson, J. R., Western Union Telegraph Co., San Francisco, Calif.
Pettit, Z. T., Los Angeles Gas & Electrical Corp., Los Angeles, Calif.
Phelps, M. W., Pittsburgh Transformer Co., Buffalo, N. Y.
Philipson, R. E., Electric Bond & Share Co., New York, N. Y.
Pimentel, O., Cia Minera San Rafael y Anexas, Pachuca, Hgo., Mex.
Pyle, A. J., Univ of Penna., Philadelphia, Pa.
Ragg, F. C., Textile Dyeing Co. of America, Paterson, N. J.
Ransford, H. E., Henry N. Muller Co., Pittsburgh, Pa.
Reifsnyder, S. E., Chas. Cory & Son, Inc. Philadelphia, Pa.
Reilly, F. J., Tork Co., New York, N. Y.
Rodgers, K. F., Bell Tel. Laboratories, Inc., New York, N. Y.
Royere, J. E., Electrical Testing Laboratories, New York, N. Y.
Schroeder, E. H., Western Electric Co., Inc., Philadelphia, Pa.
Scott, T. W., Baltimore & Ohio R. R., Connellsville, Pa.
Siskind, R. P., Harvard Engineering School, Cambridge, Mass.
Smith, H. L., Southern Ontario Gas Co., Merlin, Ont., Can.
Snow, H. B., Public Service Production Co., Newark, N. J.
Snyder, F. L., Westinghouse Elec., & Mfg. Co., Sharon, Pa.
Spector, B., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Steeb, G., Niagara Lockport & Ontario Power Co., Gardenville, N. Y.
Steinkamp, W., X-Ray & Electro Medical Equipment, Rochester, N. Y.
Stempfle, F., 105 W. 57th St., New York, N. Y.
Stevens, E. J., Jr., Gurney Elevator Co., Inc., New York, N. Y.
Stinson, M. J., Montville Power Station, Uncasville, Conn.
Szappanyos, A., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Thomas, R. E., Westinghouse Elec. & Mfg. Co., Detroit, Mich.
Thompson, C. S., (Member), Consulting Engineer, Oklahoma City, Okla.
Thompson, W. S., Michigan Bell Telephone Co., Detroit, Mich.
Torres, S. E., Transcontinental Pet. Co., La Barra Refinery, Tampico, Mexico
Tracy, G. F., University of Wisconsin, Madison, Wis.
Trainor, J. F., Underwriters Laboratories, Boston, Mass.
Turner, W. F., Brooklyn Edison Co., Brooklyn, N. Y.
Wagner, V. C., Fischbach & Moore, Inc., New York, N. Y.
Wardell, D. P., National Sugar Refinery Co., Long Island City, N. Y.
Washburn, J. C. B., Narragansett Elec. Lighting Co., Providence, R. I.
Watling, R. G., So. California Telephone Co., Los Angeles, Calif.
Watson, H. K., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Westbye, J., (Member), Gibbs & Hill, New York, N. Y.
Westbrook, J. A., Commonwealth Edison Co., Chicago, Ill.
Wiley, F. H., (Member), Westinghouse Elec. & Mfg. Co., Denver, Colo.
Williams, G. S., Central Maine Power Co., Augusta, Me.
Williard, J. A., Philadelphia Electric Co., Philadelphia, Pa.
Wissmann, J. T., Radio Corp. of America, Riverhead, N. Y.
Womer, C. E., Shamokin-Mt. Carmel Transit Co., Boston, Mass.
Wood, G. E. Chelsea Hotel, New York, N. Y.
Woods, O. B., Newfoundland Power & Paper Co., Deer Lake, Newfoundland
Zielinski, H., Kny-Scheerer Corp. of America, New York, N. Y.
Zimmerman, E. F., Southwestern Bell Tel. Co., St. Louis, Mo.
Total 143

Foreign

Blythe, G. E. K., Messrs. C. A. Parsons & Co., Ltd., Heaton, Newcastle-on-Tyne, Eng.
Donaldson, L. J., Brown, Boveri & Co., Ltd., of Switzerland; For mail, Sidney, N. S. W.
Forrest, F., (Member), Birmingham Corp., Birmingham, Eng.
Gallego, A., (Member), Obras Sanitarias de la Nacion, Buenos Aires, Arg. Rep., S. Amer.
Haskell, M. E., Morajee Soculdass & Co., Bombay 1, India
Hemsley, S. H., Messrs. Ferranti, Ltd., Hollinwood, Lancashire, Eng.
Hussain, S. M., (Member), Bellary Electric Supply Co., Ltd., Bellary, Madras Presidency, India
Lebon, J. D.,The Burmah Oil Co.'s Power Station, Thittabwe, Nyaunghla P. O., Upper Burma, India.
Lott, H. C., (Member), Balfour, Beatty & Co., Ltd., London, E. C. 4, Eng.
Lydon, R. J. B., Central Technical College, Brisbane, Queensland, Aust.
Martinov, Central & Substa. Dept., State Electrotechnical Trust, Leningrad, Russia
Moitinho, R., Electrical Public Services, Estado do Rio de Janeiro, Nictheroy, Brazil
Pougy, A. M., Cia Docas de Santos, Santos, Brazil, So. America
Reid, M., St. George County Council, Kogarah, Sydney, Australia
Thompson E., St. George County Council, Kogarah, Sydney, Australia
Webb, H., (Member), Wanganui-Rangitikei Elec. Pr. Board, Wanganui, N. Z.
Total 16

STUDENTS ENROLLED

Abbott, John N., Univ. of Delaware
Alexander, Philip, Jr., Alabama Poly. Inst.
Anders, Milton, Univ. of Minnesota
Andersen, John A., Brooklyn Poly. Inst.
Archer, George E., Georgia School of Technology
Arima, John K., Univ., of Washington
Baker, Harold D., Drexel Inst.
Baldwin, Rex G., Ohio State Univ.
Barnard, Marill M., Texas A. & M. College
Barrera B., Fernando, Escuela de Ingenieros Mecanicos y Electricistas
Bausman, Willard, Univ. of Southern California
Beckett, W. J. Oklahoma A. & M. College
Bennett, Leon S., Northeastern Univ.
Bickford, Chaloner L., Northeastern Univ.
Biggi, Louis C., Villanova College
Bitter, A. Romeyn, Univ. of Denver
Black, Leonard J., Univ. of California
Blakeslee, Theodore M., Univ. of Southern Calif.
Bohn, Louis G., Jr., Stevens Inst. of Tech.
Bolster, William, Univ. of Washington
Bonanno, Joseph L., Stevens Inst.
Bracken, William W., Washington Univ.
Brandt, Clifford A., Univ. of Minnesota
Brandt, Ralph H., Stanford Univ.
Brookins, Harry, Queens Univ.
Brown, Joseph R., Clarkson College of Tech.
Brown, Richard H., Yale Univ.
Brunner, Harry C., Washington Univ.
Bruzina, Russell, Milwaukee School of Engg.
Buckley, Arthur, Northeastern Univ.
Byrd, Oscar, Univ. of Florida
Campbell, Neil H., Univ. of Southern Calif.
Carlisle, William H., Jr., Mass Inst. of Tech.
Carpenter, Earl, M., Tufts College
Cerveny, Philip F., State College of Washington
Chalmers, Archibald C., Northeastern Univ.
Chrestensen, Carl E., Univ. of Wisconsin
Christison, Donald C., Univ. of Wisconsin
Cifuentes, Joseph, Columbia Univ.
Clark, Fred Stevens, Univ. of Minnesota
Clark, Roy W., Washington State College
Cole, David D., Univ. of Michigan
Collett, Nelson E., Univ. of Calif.
Conners, George W., Jr., Stanford Univ.
Connors, Edward T., Catholic Univ. of America
Corey, Raymond E., Univ. of New Hampshire
Coulson, Arthur G., Univ. of Nebraska
Crabs, Lester J., Oklahoma A. & M. College
Crawford, Duncan A., Mass Inst. of Tech.
Crowley, Homer L., Univ. of Calif.
Davis, Ralph L., Milwaukee School of Engg.
De Jordan, Roy, Univ. of Wisconsin
Dickinson, Raymond L., Yale Univ.
Dodd, Nathan M., Univ. of Nebraska
Dracopoulos, P. T., Yale Univ.
Driscoll, John J., Mass. Inst. of Tech.
Du Bois, J. Harry, Univ. of Minnesota
Dunstan, Gilbert H., Univ. of Southern Calif.
Dyson, Horace R., Mass. Inst., of Tech.
Dytrt, Lumir, Iowa State College
Ellingwood, Mallard E., Northeastern Univ.
Erskine, Arthur J., Univ. of Wisconsin
Farmer, J. Woodruff, Northeastern Univ.
Firestone, Samuel, Univ. of Michigan
Fitz Gerald, Donald D., Yale Univ.
Fitzgerald, Edward P., Johns Hopkins Univ.
Flodin, Carl R., Jr., Univ. of Washington
Frandsen, Dallas J., Univ. of Colorado
Gail, Charles P., Mass. Inst., of Technology
Gast, Raymond W., Stevens Inst. of Tech.
Gilmore, Frank W., Mass. Inst. of Tech.
Gipson, Bernard, Univ. of Southern California
Glenn, Bruce, Oklahoma A. & M. College
Gould, David W., Northeastern Univ.
Graham, Veto J., Univ. of Texas
Gray, Truman S., Univ. of Texas
Grimes, Edgar S., Northeastern Univ.
Grogan, Russell M., Catholic Univ. of America
Gubin, I. Paul, Univ. of Calif.
Gupta, Birjendr N., Mass. Inst. of Technology
Hahn, Paul, College of the City of New York
Halloran, Thomas V., Villanova College
Hampe, George W., Washington Univ.
Hansen, John C., Univ. of Utah
Hardy, Edward J., Case School of Applied Science
Harry, Joseph Paul, Univ. of Southern California
Hawley, Thomas S., Catholic U. of Washington
Hayley, Frank D., Alabama Poly. Inst.
Hemmenway, Donald L., Northeastern Univ.
Hicks, James C., Northeastern Univ.
Hodge, Frederic G., Univ. of Calif.
Holder, Lyman F., Univ. of Wisconsin
Horton, Hal M., Oklahoma A. & M. College
Hovey, Bertram, Univ. of Minnesota
Hovick, Robert L., Univ. of Wyoming
Hughes, John G., Virginia Poly. Inst.
Hulsebus, Albert, Univ. of North Dakota
Hummel, Frank S., Univ. of Utah
Hurteau, John E., Milwaukee School of Engg.
Jacobson, Morris, Northeastern Univ.
Jepson, Milton W., Northeastern University
Johnson, Gustave F., Univ. of Minnesota
Jones, Archibald L., Northeastern Univ.
Jones, Clifton E., Univ. of Delaware
Jones, Fred, Georgia Tech.
Jones, John A., Villanova College
Jurgens, William F., Broooklyn Poly. Inst.
Karrer, Lawrence Edison, Univ. of Washington
Kasai-Girey, Alim N., Univ. of Southern Calif.

Keane, Paul H., Univ. of Calif.
Keeler, George H., Georgia Tech.
Kersey, Wyatt, D., Georgia Tech.
Kietzmann, Emil A., Kansas University
King, Wilfred T., Univ. of Illinois
Kingston, Clarence R., Cornell Univ.
Kinsburg, Boris J., Univ. of Southern Calif.
Kirkbride, Louis A., Univ. of Nebraska
Kleff, Arnold J., Jr., Johns Hopkins Univ.
Knighton, William S., Johns Hopkins Univ.
Knox, Ira L., Alabama Poly. Inst.
Koch, Percy J., Washington State College
Koerper, Erhardt C., Univ. of Calif.
Kolisch, Emil, Mass. Inst. of Technology
Kranzfelder, Edgar, Columbia Univ.
Krotser, George R., Leland Stanford Univ.
Lakatos, Emory, Stevens Inst.
Lane, John P., Yale Univ.
Larason, George E., Oklahoma Agri. & Mech. College
Lawrence, Philip, Stevens Inst., of Tech.
LeCompte, Joe., State College of Washington
Lenzen, Theodore L., Stanford Univ.
Little, Chester B., Univ. of Southern Calif.
Longley, Richard M., Univ. of New Hampshire
Loxley, Benjamin R., California Inst. of Tech.
Lyman, Harold T., Jr., Yale Univ.
Macferran, Mabel, Stanford Univ.
MacLean, Kenneth G., Northeastern Univ.
MacLeod, Donald R., Queens Univ.
Madden, Harry E., Univ. of Calif.
Madeheim, Huxley, Stevens Inst. of Tech.
Maedel. George F., Jr., Columbia Univ.
Mahan, Guy S., Rose Poly. Inst.
Maki, Hjalmar S., Univ. of New Hampshire
Mancini, Philip S., Mass. Inst. of Tech.
McCall, D. B., Jr., Univ. of Texas
McClung, Joseph E., McGill Univ.
McClure, Lindley W., McGill Univ.
McCormick, Lawrence O., Johns Hopkins Univ.
McCune, Francis E., Univ. of Calif.
McElwee, James F., Jr., Georgia Tech.
McFarland, G. Earl, Milwaukee School of Engg.
McFarland, James D., Univ. of Texas
McLean, Corbett, Stanford Univ.
McMullen, Robert B., Univ. of Washington
McRae, Horace T., Univ. of New Hampshire
Mendez, August R., Univ. of Minnesota
Messenger, Uram H., Oregon State Agri. College
Meyer, Vincent J., Univ. of Southern California
Meyers, Stanley T., Steven Inst. of Tech.
Miller, Verne B., Univ. of Southern Calif.
Mills, Roy V., Johns Hopkins Univ.
Montin, Andy G., Univ. of Calif.
Moody, Frank B., Univ. of New Hampshire
Moses, Marlowe G., Univ. of Minnesota
Munzer, Louis F., College of the City of New York
Nason, Horace E., Mass. Inst. of Tech.
Nathan, Simon S., Cornell Univ.
Nergaard, Leon S., Univ. of Minnesota
Newton, Oscar A., Newark Tech. School
Nichol, J. M. D., Virginia Poly. Inst.
Nilson, Leonard V., Purdue Univ.
Niswander, Roy Frank, Univ. of Calif.
Nussbaum, H. Weldon, Stanford Univ.
Obergfell, Frederick, Cooper Union Inst.
Obold, Francis X., Catholic Univ. of America
O'Brien, Joseph E., Catholic Univ. of America
Oudahvihin, Michael, Univ. of Calif.
Paradis, Ernest J., Univ. of Washington
Park, William H., Univ. of Calif.
Payette, Sedric, Univ. of Washington
Pflug, Charles E., Univ. of Nebraska
Pierson, Israel S., Univ. of Utah
Poole, Arthur B., Cornell Univ.
Priebe, Lloyd H., Univ. of Washington
Probst, Henry O., Newark Technical School
Rancourt, Louis E., Catholic Univ. of America
Rapport, Adolph H., College of the City of New York
Rayburn, Gordon I., Univ. of Southen Calif.
Raynolds, David W., Univ. of Tenn.
Regalia, William G., Univ. of Calif.
Reynolds, Wallace B., Univ. of Calif.
Root, Kenneth W., Northeastern Univ.
Ringstrom, George H., Univ. of Minnesota
Ross, Arthur H., Cornell Univ.
Rudolph, Frederic C., Stevens Inst. of Tech.
Ryan, Harold J., Mass. Inst. of Tech.
Rydzewski, Charles J., Michigan State College
Sargent, Wilbur S., Univ. of Southern Calif.
Sartain, Clarence M., University of Texas
Sawyer, Chester B., Northeastern Univ.
Sawyer, Stanley P., Mass Inst. of Technology
Schultheis, John R., Johns Hopkins Univ.
Scott, Kirk K., Univ. of Wyoming
Sharp, James G., Jr., Stanford Univ.
Shutt, Charles C., Iowa State College
Siemers, Henry K., Stevens Inst. of Technology
Skinner, Virginius S., University of Texas
Slavin, Samuel B., Univ. of Calif.
Slawson, Kenneth H., Cornell Univ.
Smith, E. Elwood, Univ. of Southern California
Smith, Glen R., Ohio Univ.
Smith, Jerome C., Univ. of Minnesota
Smith, Leonard A., Northeastern Univ.
Sorem, Clifford, Univ. of Calif.
Sparks, William S., Catholic Univ. of America
Stacy, Warren C., Alabama Poly. Inst.
Stanley, George W., Brown Univ.
Stark, Emil, Brooklyn Poly. Inst.
Starr, Frank C., Univ. of Nebraska
Stevenson, Howard R., Univ. of Michigan
Stiffler, John C., Penn. State College
Stott, Kenneth M., Univ. of Calif.
Strout, Phillips E., Northeastern Univ.
Swiedom, K. Louis, Univ. of Texas
Tacy, Arthur J., Mass. Inst. of Tech.
Talbott, Forrest H., Purdue Univ.
Talcott, F. Wayne, Clarkson College of Tech.
Tappan, Thomas C., Univ. of New Hampshire
Tate, Virgil R., Milwaukee School of Engineering
Trost, Frederick, J., Columbia Univ.
Turney, Hugh W., Columbia Univ.
Upham, Walter E., Northeastern Univ.
Upton, Edward W., Univ. of Calif.
Van Kirk, Charles A., Univ. of Calif.
Volckhausen, Walter J., Stevens Inst. of Tech.
Waller, Raymond D., Washington State College
Walsh, Lincoln G., Stevens Inst. of Tech.
Walter, Ralph E., Univ. of Washington
Walther, Austin, Univ. of California
Waltz, Frank H., Penn. State College
Ware, Wallace S., Univ. of New Hampshire
Warner, Henry B., Univ. of Minnesota
Watkeys, William B., Penn State College
Webber, Clyde H., Univ. of Minnesota
Weir, George E., Stevens Inst. of Tech.
Weisser, Lester H., Univ. of Southern California
Weom, L. A., Univ. of Minnesota
Williston, Everett S., Northeastern Univ.
Witts, Seth, N., Univ. of Minnesota
Worden, Arnold W., Northeastern Univ.
Worel, Frank, Univ. of Michigan
Wright, Sherwin H., Univ. of Calif.
Wyeth, Adney, Milwaukee School of Engineering
Zuch, Helmuth W., Univ. of Texas

LIST OF SECTIONS

Name	Chairman	Secretary
Akron	Ralph Higgins	John Grotzinger, 64 Marguerite Ave., Cuyahoga Falls, Ohio
Atlanta	W. E. Gathright	W. F. Oliver, Box 2211, Atlanta, Ga.
Baltimore	W. B. Kouwenhoven	R. T. Greer, Madison St. Building, Baltimore, Md.
Boston	J. W. Kidder	W. H. Colburn, 39 Boylston Street, Boston, Mass.
Chicago	Carl Lee	B. E. Ward, Room 1679, 230 S. Clark St., Chicago, Ill.
Cincinnati	H. C. Blackwell	E. S. Fields, Union Gas & Electric Co., Cincinnati, Ohio
Cleveland	Chester L. Dows	J. F. Schnable, 3503 Mapledale Ave., Cleveland, Ohio
Columbus	R. J. B. Feather	W. T. Schumaker, 25½ North High St., Columbus, Ohio
Connecticut	A. A. Packard	A. E. Knowlton, Dunham Laboratory, Yale University, New Haven, Conn.
Denver	V. L. Board	R. B. Bonney, Telephone Building, P. O. Box 960, Denver, Colo.
Detroit-Ann Arbor	G. B. McCabe	Harold Cole, Detroit Edison Co., 2000 Second Ave., Detroit, Mich.
Erie	H. J. Hansen	L. H. Curtis, General Electric Co., Erie, Pa.
Fort Wayne	E. L. Gaines	D. W. Merchant, General Electric Co., Fort Wayne, Ind.
Indianapolis-Lafayette	H. M. Anthony	J. B. Bailey, 48 Monument Circle, Indianapolis, Ind.
Ithaca	J. G. Pertsch, Jr.	Geo. F. Bason, Cornell University, Ithaca, N. Y.
Kansas City	F. S. Dewey	Henry Nixon, 509 Mutual Building, Kansas City, Mo.
Lehigh Valley	W. H. Lesser	G. W. Brooks, Pennsylvania Power & Light Co., Allentown, Pa.
Los Angeles	R. A. Hopkins	R. E. Cunningham, 1725 Camden Ave., So. Pasadena, Calif.
Lynn	E. D. Dickinson	F. S. Jones, General Electric Co., Lynn, Mass.
Madison	L. E. A. Kelso	Leo J. Peters, University of Wisconsin, Madison, Wis.
Mexico	E. F. Lopez	H. Larralde, Isabel La Catolica, 33 Mexico, D. F., Mexico
Milwaukee	H. R. Huntley	L. F. Seybold, 446 Public Service Building, Milwaukee, Wis.
Minnesota	A. G. Dewars	J. E. Sumpter, 919-23 Security Building, Minneapolis, Minn.
Nebraska		C. W. Minard, 509 Electric Building, Omaha, Neb.
New York	H. A. Kidder	H. V. Bozell, Bonbright & Co., 25 Nassau St., New York, N. Y.
Niagara Frontier	J. Allen Johnson	A. W. Underhill, Jr., 606 Lafayette Building, Buffalo, N. Y.
Oklahoma	E. R. Page	C. C. Stewart, Oklahoma Gas & Elec. Co., Norman, Okla.
Panama	L. W. Parsons	I. F. McIlhenny, Box 413, Balboa Heights, C. Z.
Philadelphia	Nathan Shute	R. H. Silbert, 2301 Market St., Philadelphia, Pa.
Pittsburgh	G. S. Humphrey	W. C. Goodwin, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Pittsfield	E. D. Eby	C. H. Kline, General Electric Co., Pittsfield, Mass.
Portland, Ore.	L. W. Ross	J. C. Henkle, Hawthorne Building, Portland, Ore.
Providence	W. P. Field	F. N. Tompkins, Brown University, Providence, R. I.
Rochester	A. E. Soderholm	Earl C. Karker, Mechanics Institute, Rochester, N. Y.

LIST OF SECTIONS—*Continued*

Name	Chairman	Secretary
St. Louis	Fred D. Lyon	Ralf T. Toensfeldt, 311 City Hall, St. Louis, Mo.
San Francisco	R. C. Powell	A. G. Jones, 807 Rialto Building, San Francisco, Calif.
Saskatchewan	E. W. Bull	W. P. Brattle, Dept. of Telephones, Parliament Bldgs., Regina, Sask.
Schenectady	W. J. Davis, Jr.	W. E. Saupe, Bldg. No. 41, General Electric Co., Schenectady, N. Y.
Seattle	E. A. Loew	C. E. Mong, 505 Telephone Building, Seattle, Wash.
Sharon	W. M. Dann	L. H. Hill, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Southern Virginia	W. S. Rodman	J. H. Berry, 1338 Rockbridge Ave., Norfolk, Va.
Spokane	G. S. Covey	Richard McKay, Washington Water Power Co., Lincoln & Trent, Spokane, Wash.
Springfield, Mass.	R. P. King	J. Frank Murray, 251 Wilbraham Ave., Springfield, Mass.
Syracuse	W. C. Pearce	L. N. Street, College of Applied Science, Syracuse University, Syracuse, N. Y.
Toledo	A. H. Stebbins	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio
Toronto	L. B. Chubbuck	W. L. Amos, Hydro-Elec. Power Commission, 190 University Ave., Toronto, Ont.
Urbana	C. A. Keener	J. T. Tykociner, 300 Electrical Laboratory, University of Illinois, Urbana, Ill.
Utah	John Salberg	D. L. Brundige, Utah Pr. & Lt. Co., Box 1790, Salt Lake City, Utah.
Vancouver	A. Vilstrup	C. W. Colvin, B. C. Elec. Railway Co., Hastings St., Vancouver, B. C.
Washington, D. C.	A. F. E. Horn	L. E. Reed, Potomac Elec. Pr. Co., 14th & C Sts., N. W., Washington, D. C.
Worcester	E. T. Harrop	Fred B. Crosby, 15 Belmont St., Worcester, Mass.
Total 51		

LIST OF BRANCHES

Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
Alabama Polytechnic Institute, Auburn, Ala	C. W. McMullan	Jas. B. Davis	W. W. Hill
Alabama, University of, University, Ala	C. E. Rankin	Sewell St. John	
Arizona, University of, Tucson, Ariz	C. A. Rollins	J. W. Cruse	Paul Cloke
Arkansas, University of, Fayetteville, Ark	R. McFarland	J. Demarke	W. B. Stelzner
Armour Institute of Technology, Chicago, Ill	H. J. Prebensen	W. A. Dean	D. P. Moreton
Brooklyn Polytechnic Institute, Brooklyn, N. Y	J. C. Arnell	J. H. Diercks	Robin Beach
Bucknell University, Lewisburg, Pa	T. J. Miers	C. A. Rosencrans	W. K. Rhodes
California Institute of Technology, Pasadena, Calif	W. A. Lewis	A. E. Schueler	R. W. Sorensen
California, University of, Berkeley, Calif	E. A. Fenander	C. F. Dalziel	T. C. McFarland
Carnegie Institute of Technology, Pittsburgh, Pa	G. L. LeBaron	H. E. Ashworth	B. C. Dennison
Case School of Applied Science, Cleveland, O	C. A. Baldwin	A. B. Anderson	H. B. Dates
Catholic University of America, Washington, D. C	B. J. Kroeger	J. E. O'Brien	T. J. MacKavanaugh
Cincinnati, University of, Cincinnati, O	F. Sanford	W. C. Osterbrock	W. C. Osterbrock
Clarkson College of Technology, Potsdam, N. Y	W. R. MacGregor	L. G. Carney	A. R. Powers
Clemson Agricultural College, Clemson College, S. C	B. V. Martin	W. H. Sudlow	S. R. Rhodes
Colorado State Agricultural College, Ft. Collins, Colo	C. O. Nelson	D. W. Asay	
Colorado, University of, Boulder, Colo	O. V. Miller	L. E. Swedlund	W. C. DuVall
Cooper Union, New York, N. Y	F. H. Miller	H. T. Wilhelm	
Denver, University of, Denver, Colo	Earl Reed	R. L. Kuhler	R. E. Nyswander
Drexel Institute, Philadelphia, Pa	E. B. Middleton	W. N. Richards	E. O. Lange
Florida, University of, Gainesville, Fla	O. B. Turbyfill	R. Theo. Lundy	J. M. Weil
Georgia School of Technology, Atlanta, Ga	S. M. Thomas	C. E. Burke	E. S. Hannaford
Idaho, University of, Moscow, Idaho	R. C. Beam	James Gartin	J. H. Johnson
Iowa State College, Ames, Iowa	P. E. Benner	H. J. Biddulph	F. A. Fish
Iowa, University of, Iowa City, Iowa	L. Dimond	A. C. Boeke	A. H. Ford
Kansas State College, Manhattan, Kan	H. M. Porter	E. J. Weeks	C. E. Reid
Kansas, University of, Lawrence, Kans	K. R. Krehbiel	K. B. Clark	G. C. Shaad
Kentucky, University of, Lexington, Ky	J. A. Weingartner	C. E. Albert	
Lafayette College, Easton, Pa	A. H. Gabert	F. G. Keim	Morland King
Lehigh University, S. Bethlehem, Pa	F. G. Kear	J. H. Shuhart	J. L. Beaver
Lewis Institute, Chicago, Ill	O. D. Westerberg	R. G. Raymond	F. A. Rogers
Maine, University of, Orono, Me	S. B. Coleman	H. S. McPhee	W. E. Barrows, Jr.
Marquette University, Milwaukee, Wis	C. H. Legler	M. J. Smith	J. F. H. Douglas
Massachusetts Institute of Technology, Cambridge, Mass	Stuart John	H. W. Geyer	W. H. Timbie
Michigan State College, East Lansing	H. C. Roberts	R. A. Bailey	L. S. Foltz
Michigan, University of, Ann Arbor, Mich	M. H. Nelson	S. L. Burgwin	B. F. Bailey
Milwaukee, Engineering School of, Milwaukee, Wis	S A. Moore	B. J. Chromy	B. A. Bovee
Minnesota, University of, Minneapolis, Minn	R. L. Christen	A. A. Lee	H. Kuhlmann
Missouri, University of, Columbia, Mo	M. P. Weinbach	L. Spraragen	M. P. Weinbach
Missouri School of Mines and Metallurgy, Rolla, Mo	W. J. Maulder	R. P. Baumgartner	I. H. Lovett
Montana State College, Bozeman, Mont	T. A. Van Noy	J. A. Thaler	J. A. Thaler
Nebraska, University of, Lincoln, Neb	R. Worrest	C. J. Madsen	F. W. Norris
Nevada, University of, Reno, Nev	Lloyd Crosby	R. C. Samuels	S. G. Palmer
New York, College of the City of, New York, N. Y	J. Wilson	J. Leipziger	Harry Baum
New York University, New York, N. Y	W. R. Steeneck	H. A. Weber	J. Loring Arnold
North Carolina State College, Raleigh, N. C	F. P. Dickens	H. Baum	
North Carolina, University of, Chapel Hill	M. L. Murchison	D. M. Holshouser	P. H. Daggett
North Dakota, University of, University	V. L. Cox	O. B. Medalen	D. R. Jenkins
Northeastern University, Boston, Mass	F. W. Morley	L. C. Tyack	W. L. Smith
Notre Dame, University of, Notre Dame, Ind	C. A. Rogge	J. T. Burton	J. A. Caparo
Ohio Northern University, Ada, Ohio	H. N. Seslar	Frank Boulton	
Ohio State University, Columbus, O	L. W. Hendershott	F. S. Kinkead	F. C. Caldwell
Ohio University, Athens, Ohio			
Oklahoma A. & M. College, Stillwater, Okla	W. J. Beckett	Lee Rogers	Edwin Kurtz
Oklahoma, University of, Norman, Okla	F. O. Bond	E. F. Durbeck, Jr.	F. G. Tappan
Oregon Agricultural College, Corvallis, Ore	H. E. Rhoads	B. E. Plowman	F. O. McMillan
Pennsylvania State College, State College, Pa	W. L. Kochler	J. E. Hogan	L. A. Doggett

LIST OF BRANCHES—*Continued*

Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
Pennsylvania, University of, Philadelphia	J. P. Lukens	J. G. Haydock	C. D. Fawcett
Pittsburgh, University of, Pittsburgh, Pa	S. A. Swetonic	L. M. Brush	H. E. Dyche
Purdue University, Lafayette, Ind	W. O. Osbon	R. C. Parker	
Rensselaer Polytechnic Institute, Troy, N. Y	F. M. Sebast	K. C. Wilsey	F. M. Sebast
Rhode Island State College, Kingston, R. I	D. B. Brown	S. J. Bragg	Wm. Anderson
Rose Polytechnic Institute, Terre Haute, Ind	J. H. Utt	E. Letsinger	C. C. Knipmeyer
Rutgers University, New Brunswick, N. J	Stanley Hunt	S. B. Aylsworth	F. F. Thompson
South Dakota State School of Mines, Rapid City, S. D	J. V. Walrod	C. Allen	J. O. Kammerman
South Dakota, University of, Vermillion, S. D	L. J. Stverak	R. T. Brackett	B. B. Brackett
Southern California, University of, Los Angeles, Calif	J. H. Shideler	E. E. Smith	C. E. Guse
Stanford University, Stanford University, Calif	F. E. Crever	C. R. Walling	H. H. Henline
Stevens Institute of Technology, Hoboken, N. J	L. G. Walsh	H. K. Siemers	
Swarthmore College, Swarthmore, Pa	J. S. Donal, Jr.	R. W. Lafore	Lewis Fussell
Syracuse University, Syracuse, N. Y	K. N. Cook	R. H. Watkins	C. W. Henderson
Tennessee, University of, Knoxville, Tenn	D. H. Sneed	H. B. Shultz	
Texas A. & M. College, College Station, Texas	L. H. Cardwell	C. A. Altenbern	F. C. Bolton
Texas, University of, Austin, Tex	R. M. Baker	J. D. McFarland	J. A. Correll
Utah, University of, Salt Lake City, Utah	F. C. Bates	C. E. Hoffman	J. F. Merrill
Virginia Military Institute, Lexington, Va	E. T. Morris	J. H. Diuguid	S. W. Anderson
Virginia Polytechnic Institute, Blacksburg, Va	M. R. Staley	R. M. Hutcheson	Claudius Lee
Virginia, University of, University, Va	T. M. Linville	H. M. Dixon, Jr.	W. S. Rodman
Washington, State College of, Pullman, Wash	E. L. Clark	Harry Meahl	H. V. Carpenter
Washington University, St. Louis, Mo	W. W. Braken	S. E. Newhouse, Jr	H. G. Hake
Washington, University of, Seattle, Wash	H. O. Compton	C. M. Murray, Jr.	George S. Smith
West Virginia University, Morgantown, W. Va	R. W. Beardslee	W. F. Davis	A. H. Forman
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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Disconnecting Switches.—Bulletin 25403, 4 pp. Describes the design and engineering specifications of types R and RA disconnecting switches. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Ball Bearings.—Booklet F 910, 12 pp., "Precision Ball Bearings for Fractional Horse Power Motors." The Norma-Hoffman Bearings Corporation, Stamford, Conn.

Theatrical Equipment.—Catalog M, 128 pp. Describes a complete line of lighting specialties and lighting effects for the stage, for theatres, motion picture studios, window displays, show rooms, exhibitions, outdoor flood lighting, and many other applications. Kliegl Bros., 321 West 50th Street, New York.

Instruments.—Catalog 8931, 24 pp. Describes various instruments of medium and small size for a number of purposes, including a-c. and d-c. applications in radio work, in checking operation of motor starters and starting controllers, in power plants to check opens and shorts on relay circuits, and many others. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Ground Wire Clamps.—Circular describes newly developed ground wire clamp particularly adaptable to "Copperweld" ground rods. The clamps are permanently secured to the ground rods by mechanical means, eliminating the use of soldered connections, although solder may be used, if desired. Exceptional strength is claimed for the new clamp. Copperweld Steel Company, Rankin, Pa.

Power Factor.—Bulletin GEA 232, 32 pp., "Power Factor and Means for Its Improvement." This booklet presents in a simple and systematic manner authoritative information on means for power factor improvement in industrial plants. It is a practical treatise on power factor with the mathematics reduced to simple arithmetic. General Electric Company, Schenectady, N. Y.

Static Condensers.—Bulletin 1670A, 24 pp., "Static Condensers for Power Factor Correction." One section is devoted to a discussion of power factor, its correction and the selection of corrective equipment; another part describes LD static condensers; the third part is devoted to low-voltage static condensers, describing the construction assembly and application. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Lighting Data.—A series of bulletins. LD 101B, 28 pp., "Effect of Maintenance and Color of Surroundings on Resultant Illumination;" LD 103C, 36 pp., "The Lighting of Show Windows and Show Cases;" LD 126A, 40 pp., "Lighting for Recreations;" LD 146A, 48 pp., "Stage Lighting;" LD 0A, 16 pp., "Index of Information Contained in Lighting Data Bulletins as of January 1, 1926." Edison Lamp Works of General Electric Company, Harrison, N. J.

NOTES OF THE INDUSTRY

The Sterling Varnish Company, Pittsburgh, Pa., announces that J. S. Applegate, formerly of the Wagner Electric corporation has joined its staff as metallurgical engineer and consultant for users of insulating varnishes.

New G. E. Electric Plant at Los Angeles.—The new General Electric service plant in Los Angeles at 5201 Santa Fe Avenue was formally opened on March 23. This new plant, comprising three buildings, a three-story warehouse, a two-story office building and a service shop, will have a total of 88,000 square feet of floor space.

The American Brown Boveri Electric Corporation, New York, has appointed L. J. Galbreath to take charge of publicity and sales promotion, and as assistant to Earl G. Hines, recently appointed general sales manager. Mr. Galbreath was formerly connected with the Bridgeport Brass Company.

Increased Power Demands in the South.—It has been found necessary to add considerably to the central station facilities this year in several sections of the south. In Florida two new stations have been built totalling 75,000 kw., and in Texas additional turbines totalling 50,000 kw. are being added to the central stations of Dallas and Houston. All the new turbines, three of 25,000 kw. capacity, and two 12,500 kw. units, will be furnished by the General Electric Company.

The Okonite Company, Passaic, N. J., has received an order from the Puget Sound Power & Light Company for 46,800 feet of three-conductor submarine armored cable which will be used to span Puget Sound between Edmonds, on the mainland side, and President's Point, on the Olympic Peninsula, and thus connect the properties which the company recently acquired on the peninsula with the mainland system of interconnected power plants. Two cable connections will be made between the points mentioned and each cable will be capable of furnishing 10,000 h. p. The total weight of the cable will be approximately 750,000 pounds.

Keel Laid of New Electric Passenger Ship.—The keel of the first large electric passenger ship was laid at Newport News, March 20, at the plant of the Newport News Shipbuilding & Dry Dock Company. The vessel, the largest commercial craft built in the United States, will be the first of three sister ships, costing approximately $21,000,000, and will enter the New York California passenger trade in 1927. The new liner will be 601 feet long and will have a speed of 17 knots. Oil burners will furnish steam to two 9000 horse power General Electric turbine generators which will drive the motors connected to the two propellers.

Westinghouse Adds to Mansfield Plant.—A new four-story brick and concrete building with a floor space of 142,600 square feet, has recently been added to the Mansfield plant of the Westinghouse Electric and Manufacturing Company. The new manufacturing unit, which is of the most modern fireproof construction, will be devoted to the construction and assembly of ranges and electric irons. With the addition of this building, the Westinghouse plant at Mansfield has now a total floor space of 330,530 square feet, or seven and a half acres, devoted to the manufacturing of electric ware, hotel appliances, ranges and safety switches.

G. E. Suggestion Awards.—Awards totalling $38,938 were paid 3433 employees of the General Electric Company during 1925 for suggestions made by workers which improved working conditions or tended to increase the efficiency of the company's operations. During the year 11,325 suggestions were offered, of which more than 30 per cent were accepted. During the previous year 12,217 suggestions were made and 26 per cent accepted, and in 1923 but 21 per cent of those offered were accepted. The awards, which ranged up to $500, were paid at the option of the recipient either in cash or G-E Employees Securities Corporation bonds, which yield 8 per cent so long as the original holder remains in the employ of the company.

Foote, Pierson & Company, Inc., New York, manufacturers of photometers and electrical instruments, at a recent annual meeting elected George F. Lewis, president, formerly secretary and treasurer; Malcolm G. Pierson, vice-president and secretary; William R. Stout, assistant secretary and assistant treasurer. Mr. Lewis, a son of Colonel Lewis, inventor of the Lewis machine gun, succeeds Henry G. Pierson, who served as president of the company since its incorporation, and who was made Chairman of the Board. Mr. Lewis was in active service during the war and later he commanded the Engineering Officers Training School at Fort A. A. Humphrey, Va., with the rank of Lieutenant-Colonel. Malcolm G. Pierson is a son of the former president and has been acting as general sales manager. Mr. Stout has been associated with the company for the past twenty years acting as cashier.